# AMESet

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# Chapter 1: Introduction

## 1.1 What is AMESet?

If you are an advanced user, you can extend **AMESim** by adding both new icons and submodels using the separate utility **AMESet**. It provides a comprehensive graphical user interface for doing this. **AMESet** is the abbreviation of Advanced Modeling Environment - Submodel editing tool.

**AMESet** allows you to integrate new icons and submodels into the **AMESim** package so that they can be used just like standard **AMESim** icons and submodels. Producing new submodels involves writing your own code that must be in the correct format to allow **AMESim** to call it. **AMESet** creates a code skeleton in this format to which you add your own statements to implement your submodel. Using these facilities, an experienced **AMESim** user can create his own submodels according to the needs of a particular application.

## 1.2 AMESet functionality

### 1.2.1 Add and remove a component category

The standard package provides the two following categories:

- *Mechanical:*
- *Control signal and observer:*

In addition you probably have one or more optional **AMESim** libraries. This allows you to perform dynamic simulations of a variety of engineering systems. However, you can add your own categories. You can also remove a category completely from your local configuration when it is no longer needed.

### 1.2.2 Add, edit and remove a component icon in component category

This involves creating icons using the built-in *Icon designer* and then defining type and location for each of the ports in the icon. The setting of port details is fully graphical.

In addition to adding new icons in a component category, you can also modify the details of an existing component icon and its associated submodel. You can also delete an icon or submodel from a category when it is no longer needed.

### 1.2.3 Create a submodel specification

For each submodel, there must be a specification file. **AMESim** relies on the specification of a submodel to determine the details of the ports for exchanging information between the submodel and the connected submodels. **AMESet** provides you a graphical environment to set details of external variables and internal variables, details of parameters for each of the types real, integer and text, and also the requirement of discontinuities handling and time input. Once you have specified your needs, **AMESet** creates a submodel specification for you immediately.

### 1.2.4 Generate a submodel code skeleton

**AMESim** submodels must be written either in the programming language Fortran 77 or C. Of course, you can write **AMESim** submodels without using **AMESet**. However, you can benefit a lot with the use of **AMESet**:

1. The submodel specification, the function call arguments and the declaration of variables can be made totally consistent.
2. The description of the variables and parameters used in a submodel are included automatically in comment statements in the source code.
3. A template for adding a description of submodel, usage, parameter setting and code revision is also included in the source code.
4. A graphical environment for editing submodel details is provided.
5. You can set component icon port type and location interactively and graphically.
6. A great deal of time can be saved when creating new submodels.

## 1.3 Organization of this manual

Chapter 2 - **AMESim** submodels. This chapter describes the nomenclature used for **AMESim** submodels and how the code of a submodel is structured.

Chapter 3 - Getting started. This chapter shows you how to create your own **AMESim** submodels and icons by presenting a series of tutorial examples. Before reading this Chapter you should read Chapter 2.

Chapter 4 – Going Further. You should read it after Chapter 3. It gives a further examples on the use of **AMESet**.

Chapter 5 - Reference Guide for **AMESet**. This chapter contains detailed

descriptions of the facilities available in **AMESet**. It is assumed that the reader of this chapter already has some experience of using **AMESet** e.g. by doing the tutorial examples in Chapters 3 and 4.

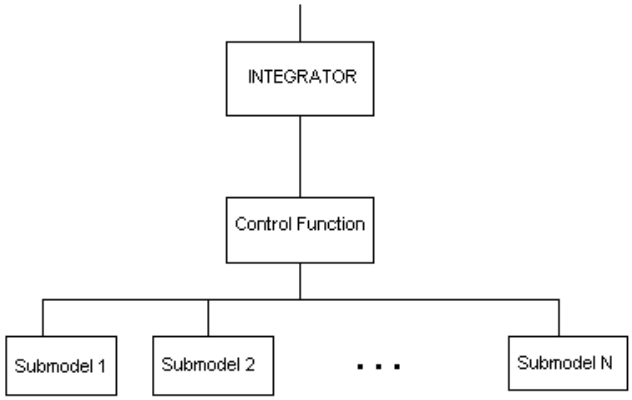
# Chapter 2: AMESim Submodels

## 2.1 Introduction

Read this chapter if you are going to produce your own submodels for **AMESim**. It describes the nomenclature used for **AMESim** submodels and how the code of a submodel is structured. You must understand these concepts before you attempt the tutorial examples of chapter 3.

## 2.2 The structure of an AMESim simulation program

**Figure 2.1: The structure of the code generated by AMESim**




When you perform a simulation using **AMESim**, computer code is produced which is specific for the engineering system you have displayed in front of you. At the core of **AMESim** is an integration algorithm, which advances the solution through time. This integration algorithm calls the submodels, which are associated with the components of the system as shown in Figure 2.1. These submodels may have been selected by **AMESim** automatically or selected manually by you. In either case, there will be computer code, which implements the mathematical equations on which the submodel is based.

The order in which the submodels are called is not normally the same as the order in which the corresponding components were added to the sketch. The **submodels are sorted** into an order that is more efficient from a computational point of view. We will return to this subject after some concepts are introduced.

The nomenclature of **AMESim** submodels will now be described.

## 2.3 Variables and parameters

During a simulation some quantities change with time. Typical examples are the pressure in a pipe and the rotary speed of a load. These quantities are called **variables**. Sometimes in a particular simulation, they are constant but, since in principle they could vary with time, they are still called variables.

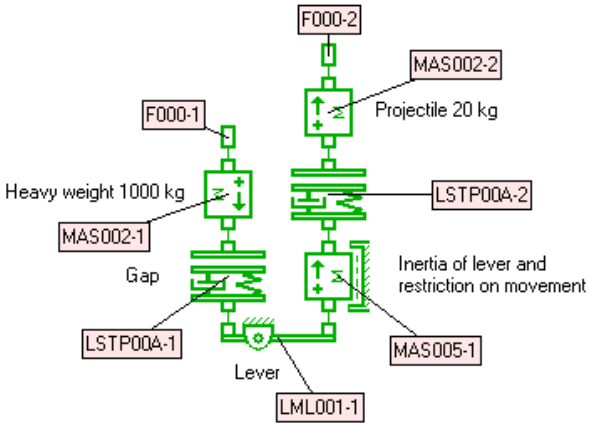
Other quantities are always fixed during a simulation run. These are called **parameters** and these quantities normally indicate a size or dimension of a component. Examples are the diameter of a pipe and mass of a load.

## 2.4 Ports and external variables

**Figure 2.2: Port numbers of an icon**

The icons of which the **AMESim** sketch of the system is built are connected together at special points on the boundaries of the icon. These points are called **ports**. There are some icons, which do not have any ports, but these are rare. Ports are numbered in a special way. When the icon is in the form when it was originally selected, the ports are numbered from the bottom left hand corner counterclockwise around the icon. In Figure 2.2 the numbering of the port of the displacement sensor icon is shown.

**Figure 2.3: A typical simple system**

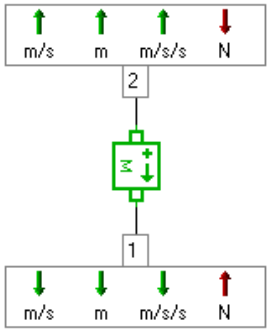


A very simple mechanical system appears in Figure 2.3 with submodel names added to the figure. The code of each component submodel has to calculate various quantities associated with the component. The mass submodel *MAS002* for example calculates the velocity in m/s, the displacement in m and the acceleration in m/s/s at each port. In order to do this, it requires information about the forces applied at the two ports. Each of these quantities is associated with a particular port and is called an **external variable**. External variables are normally available for plotting.

## 2.5 Inputs and outputs

The value of the forces applied to this mass are supplied to *MAS002* by the zero force submodel *F000* and the clearance submodel *LSTP00A*. This gives rise to the concept of dividing submodel external variables into the categories **inputs** and **outputs**.

**Figure 2.4: The inputs and outputs of MAS002**




The external variables calculated by a submodel are its outputs and for *MAS002* they are:

- *velocity port 1.*
- *displacement port 1.*
- *acceleration port 1.*
- *velocity port 2.*
- *displacement port 2.*
- *acceleration port 2.*

whereas the inputs are:

- *force port 1.*
- *force port 2.*

Remember that external variables are either inputs or outputs and allow exchange of information between submodels. The primary function of a submodel is to calculate its outputs from its inputs.

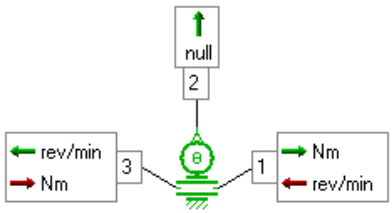
In the previous section we stated that the order in which **AMESim** calls the submodels during the integration is special. The idea is that **AMESim** tries to sort the submodels into an order such when each submodel is called, all its inputs are known. We say **tries** because sometimes no such order exists. In such circumstances we say there is an **algebraic loop** also called an **implicit loop**. **AMESim** gets over this problem by introducing special implicit variables that **break the algebraic loop**. It is hoped that the elementary **AMESim** user never has to think of these things. However, the submodel writer must be aware of this problem and must try to minimize algebraic loops.

## 2.6 Local variables and internal variables

In a typical submodel there will be many variables including some that are not external variables. Normally these are variables, which only exist inside the submodel code and are totally inaccessible outside the submodel. These are known as **local variables**.

Sometimes it is desirable to have a variable for plotting that is not an external variable because it is not needed by any another submodel. **AMESim** allows for this situation by having **internal variables**. These are like external variables but are not associated with any port and are neither inputs nor outputs.

The angle sensor submodel *ADT01*, is an example of a submodel with an internal variable.




It has three ports each with one output:

- *torque at port 1*,
- *signal output*,
- *angular velocity at port 3*.

and two inputs:

- *angular velocity at port 1*,
- *torque at port 3*.

One other variable is also calculated in *ADT01*:

- *angular displacement*.

This variable is used with a gain and an offset to compute the signal output but it is also useful in its own right. Variables like this are of sufficient significance to justify making them internal variables. In consequence, the angular displacement can be plotted if *ADT01* is included in a simulation.

A much more spectacular example of a submodel with internal variables is *RSTAT*. This has no ports and hence no external variables. It monitors various statistics concerning the integration and stores them using 14 internal variables!

**There is no concept of input/output with an internal variable.**

As you will see in the next section, variables can be classified into several types. Sometimes there is a variable, which is an explicit state variable or an implicit variable (either implicit state or constraint), but it is inappropriate to make it an external variable. These three types of variable are not computed by the submodel but rather by the integrator. In order to communicate values between the submodel and the integrator, these variables must be made internal variables and cannot be local variables, even if we are not interested in plotting graphs of them.

## 2.7 Types of variables

Further classification of external and internal variables is necessary. There are eight special types of variables, which will now be introduced:

- Explicit state variable.
- Implicit state variable.
- Constraint variable.
- Duplicate variable (simple or reversed sign).
- One-line macro variable.
- Multi-line macro variable.
- Fixed variable.

**All of the above, if they are external variables, are outputs.**

There is one type of variable which can only be an internal variable, this is an:

- Activity variable.

Any external or internal variable that does not fit into one of these categories **AMESim** refers to simply as a **basic variable**, giving a total of 9 variable types. These can be used as follows:

| Variable type | External variable | Internal variable |
|---|---|---|
| Basic | Yes | Yes |
| Explicit state | Yes | Yes |
| Implicit state | Yes | Yes |
| Constraint | Yes | Yes |
| Duplicate | Yes | No |
| One-line macro | Yes | No |
| Multi-line macro | Yes | Yes |

| Variable type | External variable | Internal variable |
|---|---|---|
| Fixed | Yes | Yes |
| Activity | No | Yes |

## 2.8 Basic Variables

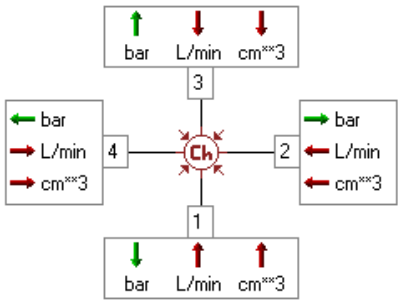
The basic variable, if it is an external variable, can be

1. an output,
2. an input,
3. an input with default,
4. an input unused.

If it is an output, it must be explicitly assigned a value. If it is an input, it will be used in the submodel to calculate the submodel outputs. The third category, input with default, is rare. The idea is that normally the value is supplied by another submodel, but if the submodel connected does not supply the value, a default value is used.

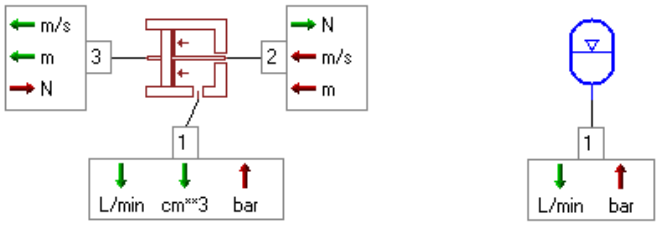
An example of submodel that uses an input with default is *BHC11* in the *HCD* library. This has external variables as follows:

**Figure 2.5: The external variables of BHC11**




The submodel represents a hydraulic chamber. At the 4 ports the inputs are a flow rate in *L/min* and a volume in $cm^3$. During normal usage we might want to connect a *BHC11* port toport 1 of the HCD piston submodel *BAP11* shown on the left but also to the hydraulic accumulator submodel HA000 shown on the right of Figure 2.6.

**Figure 2.6: Submodels we want to connect to BHC11**



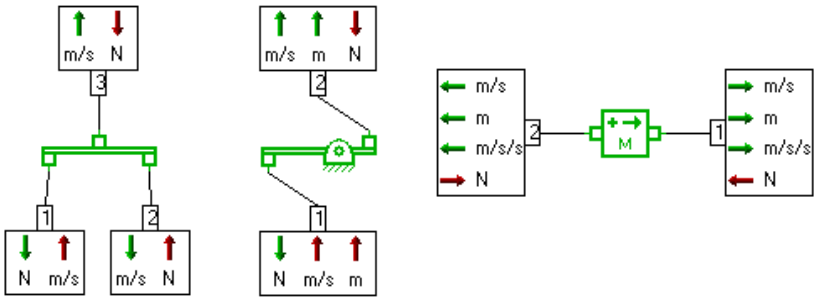

The problem is that the accumulator *HA000* does not supply a volume. The solution was make all the volumes of *BHC11* **input with defaults** (Figure 2.5), the default being 0.0 $cm^3$.

The fourth type of input/output status for a basic variable is **input unused**. An example of this is *SPR000RT*. Submodels ending with the letters *RT* are designed to be as fast as possible. Currently there are few of them but the number will grow rapidly. Extensive use is made of duplicate variables and macro variables. They have to be constructed very carefully to avoid algebraic loops and *input unused* variables play a role in this.

**Figure 2.7: The external variables of SPR000RT**

The external variables of *SPR000RT* look the same as all the other spring submodels but there is an important difference. The velocity is not used in *SPR000RT*. However, it has to be there otherwise it would not connect to a large number of other submodels. It is the convention that velocity comes before displacement which comes before acceleration. The following are typical mechanical submodels which we might hope to connect with the spring.

**Figure 2.8: Typical variables on a linear shaft port**




The one on the left would not connect with *SPR000RT* but the other two would. If *SPR00RT* had only the displacement and not the velocity it would not connect with any of them.

Internal variables can be basic variables. Remember there is no concept of input/output with a internal variable but a basic internal variable behaves like an output in that it must be assigned explicitly.

## 2.9 State Variables

State variables are explicit or implicit. In all cases there must be an **initial value** also called a **starting value** for the state variable. **State variables are not computed directly by submodels. They are computed by the integrator.**

A job of the submodel that is associated with the state is to directly or indirectly define a value of the derivative of the state. Explicit and implicit state variables differ solely in the way this assignment is made.

- For explicit states a direct assignment is made.
- For implicit states a quantity called a residual is defined. The integrator tries to make this quantity as small as possible by varying both the state variable and its derivative.

Both external and internal variables may be state variables. **If an external variable is classified as an explicit or implicit state, it is always an output**.

All state variables have titles and units. The units of the time derivative of the state can be derived from the units of the state by remembering that the simulation time always has the units second.

Implicit state variables are rare in **AMESim**. It is in general far better to use explicit state variables.

### 2.9.1 Explicit state variables

Almost all **AMESim** simulation runs involve solving differential equations. This is because many submodels are based on differential equations. For example, most of the mass submodels use a differential equation of the form

$$\frac{\delta v}{\delta t} = \frac{force}{mass}$$

where $v$ is velocity and $t$ is time. We say that $v$ is an explicit state variable. In **AMESim** nomenclature, we say that the velocity is an output of the submodel, but strictly speaking, the submodel only calculates the velocity indirectly. What the submodel does calculate is the time derivative of the velocity, $dv/dt$, as given in the formula above. From this, the **integration algorithm** calculates $v$.

## 2.9.2 Implicit state variables

These have attributes which are a combination of explicit state and constraint variables (which are described in the next section). The distinctive characteristics are as follows:

- The integrator gives the submodel an estimate for both the state variable and its derivative. Submodels use these values to compute a **residual**. The integrator then tries to make the residual zero.
- The residual has units which can be unrelated to the units of the implicit state variable.

The state is defined by a starting value and an implicit expression for the derivative which is associated with the residual in the submodel code. An example of such an expression is given below:

$$F + C\frac{\delta x}{\delta t} + K\frac{\delta x}{\delta t}\left|\frac{\delta x}{\delta t}\right| = 0$$

This expression is used to define the residual in the submodel code:

$$\varepsilon = F + C\frac{\delta x}{\delta t} + K\frac{\delta x}{\delta t}\left|\frac{\delta x}{\delta t}\right|$$

To underline the distinction we take a second example. Imagine the one-dimensional motion of an object of mass *M* kg under the action of two forces *f1 N* and *f2* N so that it moves with velocity *v1* m/s. If we used an explicit state we could have the following code:

```
/* >>>>>>>>>>>>Calculation Function Executable Statements. */
   *v1dot = (*f2 - *f1)/M;
/* <<<<<<<<<<<<End of Calculation Executable Statements. */
```

Here we explicitly define *v1dot* the derivative of *v1*. On the other hand we could use an implicit state with the following C code:

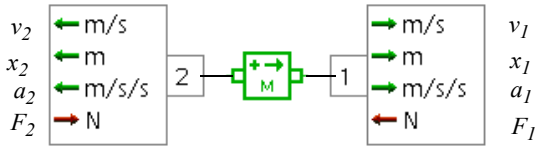
```
/* >>>>>>>>>>>>Calculation Function Executable Statements. */
    /* On entry v1dot is the derivative of v1. */

   *v1dot = M*(*v1dot)- (*f2 - *f1);

    /* On exit v1dot is the residual of v1. */
/* <<<<<<<<<<<<End of Calculation Executable Statements. */
```

The important point is that the same variable, *v1dot*, is used for the derivative and the residual. **On entry *v1dot* is an estimate (from the integrator) for the derivative of *v1* and has units m/s/s. On exit it is a residual and has units N.** In this case the first version is clearly better. There is only one small advantage of the second version. This is that it can tolerate (no problem) the value *M*=0.

Only use implicit states if there is a very good reason for doing so.

# 2.10 Constraint variables

**Figure 2.9: Constraint variables of the MAS000 submodel**




These are much rarer than explicit state variables but are sometimes useful. A simple example is in the load submodel *MAS000*. This submodel was developed from *MAS002*, which computed the one-dimension motion of a mass subject to two external forces (see Figure 2.9), in addition to its weight. For the purpose of this description we will simplify the situation and only consider the velocity and two external forces. Using the notation in the figure the time derivative of the velocity at the right port $v_1$ is given by

$$\frac{\delta v_1}{\delta t} = \frac{F_2 \angle F_1}{M}$$

The submodel works well under most circumstances but problems arise when the mass *M* becomes very small. The simulation becomes slower and slower and eventually unacceptably slow.

It is interesting to note that as the denominator tends to zero, so does the numerator. This idea is implemented in *MAS000* by adjusting $v_1$ such that

$$F_2 \angle F_1 = 0$$

This is done by declaring $v_1$ to be an algebraic or **constraint variable**. Constraint variables may be internal or external variables. If they are external variables, they are always regarded as outputs. However, submodels do not compute constraint variables as these are computed by the integration algorithm. Instead, they compute a quantity called the **residual**. This is the quantity that should be zero, but in practice would be at best a very small quantity. In *MAS000* the residual is

$$\varepsilon = F_2 \angle F_1$$

The integrator will adjust $v_1$ in an attempt to make ε zero by an iterative process. In order to do this a starting value must be provided. This is normally set using the *Change Parameters* dialog box for the submodel. Sometimes it is difficult to set this value to anything other than a very arbitrary value.

The equations being solved are now a mixture of differential and algebraic equations and are referred to as **differential algebraic equations** (d.a.e.s) as opposed to differential equations or more precisely **ordinary differential equations** (o.d.e.s).

However, often the algebraic equation part of the whole model is far more difficult to solve than the purely differential equation part. One of the problems is that an algebraic equation may have:

- a unique solution,
- no solution,
- multiple solutions or even
- an infinite number of solutions.

A d.a.e. solver has a hard task to perform and can be excused for being less reliable than an o.d.e. solver.

How does *MAS000* compare with *MAS002*? Often when the mass is very small compared with the forces it is spectacularly faster. It can fail, however, and it is very easy to think of cases where this is guaranteed to happen. Suppose we set **constant** values for the two forces as follows:

$$F_1 = 1000$$

$$F_2 = 2000$$

What value of $v_1$ will make the residual zero? Clearly this is not possible and if you try this example, you will find that the d.a.e. integrator gives up with an error message.

To summarize, constraint variables of this type can be extremely useful but must be used sparingly and with suitable warnings for the user.

Note that when **AMESim** detects an algebraic loop, it will alter the status of one or more ordinary variable to make it an constraint variable. This will break the algebraic loop.

## 2.11 Duplicates, one-line and multi-line macro variables

These three types of variable are grouped together because they are great for avoiding algebraic loops. They do this because the code that defines each of them takes on the status of a submodel in its own right and is independent of the submodel to which they belong.

Do not worry if you find this section a little confusing at first reading. As you begin to develop your own submodels and your experience grows, read this section again and it will become much clearer.

### 2.11.1 Duplicate variables

Sometimes external variables are calculated as outputs on one port but they are also needed as outputs on other ports. On other occasions an input is received on one port and is passed without modification to become an output on one or more other ports. In both these situations, the copies of the original variable are known as **duplicate variables**. The original is called the **primary variable.**

There is a further classification of duplicate variable: **simple** and **reversed sign**.

Often the duplicate variable has the same sign as the primary. However, it can be convenient to have duplicate variables with the opposite sign to the primary. This is because of the sign convention used by **AMESim**. If the primary variable was a velocity state variable, the same variable but with reversed sign might be required for another port. Note that in Figure 2.9 the variable $v_2$ is a **reversed sign duplicate** of the state variable $v_1$. Similarly $x_2$ is a reversed sign duplicate of $x_1$ and $a_2$ is a reversed sign duplicate of $a_1$. If there is no sign reversal, it is a **simple duplicate**.

> **You do not make any assignment of a duplicate variable in your submodel. This is done for you outside of the submodel.**
>
> **Use duplicate variables as much as possible.**

## 2.11.2 One-line macro

The concept of a duplicate variable involves taking the assignment of the variable outside of the submodel. As you will later in this section, simple duplicates will lead to **AMESim** (not **AMESet**) generating code like

```
v[23] = v[56];
```

for a simple duplicate and like

```
v[45] = -v[7];
```

for a reversed sign duplicate.

Sometimes we would like very much more complex assignments than this and the two macro variables provide this facility.

The one-line macro variable is as its name suggests limited to a one line assignment only. The assignment involves other suitable variables, real parameters and real stores of the submodel, time and *pi* (π).

Here is an example of code generated by **AMESim** to implement a one-line macro.

```
v[12] = (v[23] - v[56])*v[78]/1.7027648993e0;
```

**One-line macros are very useful but they make submodels difficult to debug. Use them only when there is a strong reason for doing so. Usually this is to break an algebraic loop.**

The next variable is a heavy-weight version of the one-line macro.

## 2.11.3 Multi-line macro variables

The multi-line macro is an extension of the one-line macro. It is used when you need to break up a submodel because it creates algebraic loops. It works like a one-line macro except that you write the associated code in as many lines as you need. It is actually a double function and is stored in the file of the submodel code. It can call other functions such as **AMESim** utilities or user made functions.

When a multi-line macro variable is declared, only its arguments must be entered. These arguments are chosen from the list of the submodel variables. **AMESet** writes the skeleton of the associated function automatically in the submodel code. This function can then be completed according to your needs.

At this point it is necessary to pause to see why duplicate and macro variables are useful.

## Use of duplicate and macro variables

What is the point of introducing duplicate and macro variables? Previously we stated that **AMESim** sorted submodels into a special order. We will qualify this statement by saying that **AMESim** gives to duplicate variables and macro variables the same status as a submodel. This greatly reduces the chance of algebraic loops. Remember you can look at the code generated by **AMESim**. If the system is *NAME.ame*, the generated source code is *NAME_.c*. In Figure 2. 5 is a section of code generated (which has been edited slightly to remove lines of code not strictly relevant to the present topic). Note the calls to the submodels and interspersed with the assignment of the duplicates and macro variables. The example has been taken from Chapter 4 where it is discussed in detail.

Why not make all variables duplicates or macros so that **AMESim** would not sort submodels at all but solely equations? Putting all or most of the equations into the submodel code has a lot of advantages. It makes the model much more modular and much easier to debug. (You will be writing submodels soon. Do not expect to always get them right first time.) **AMESet** actually restricts use of duplicate and macro variables to cases where there is potentially an advantage of using them.

**Figure 2.10: Duplicate and macro variables**

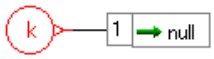
```
/* Assign the state variables y[] calculated by the integrator
   to the appropriate variables v[]. */

v[5] = y[0];                                  ← The state variable from the integrator

/* Call submodels in the order that ensures the input requirements
   of each submodel are satisfied. */
                                              The one-line macro for x only uses the
pm000_(&n);                                   state variable which is v[5]

v[4] = c1[0]*cos(v[5]*1.74532925199433e-02)+sqrt(r1[0]*r1[0]-
       c1[0]*c1[0]*sin(v[5]*1.74532925199433e-02)*sin(v[5]*1.74532925199433e-02));

v[6] = crank6_macro0_(&n, &v[5], r1, c1, J1);  ← The mult-line macro for tfratio
                                               only requires the state variable v[5]

v000_(&n);

v[3] = v[6]*v[1]*1.0471975511966e-01;          ← The one-line macro for v uses tfratio
                                               which is v[6]

dam000_(&n, &v[3], &v[7], r2);                 ← The damper

v[2] = r2[0]*(v[3]+v[7]);
v[8] = r2[0]*(v[3]+v[7]);                      ← Two one-line macros associated with the damper

crank6_(&n, &v[1], &v[2], &v[5], &dot[0], &v[6], r1, c1, J1);  ← The crank

v[0] = v[6]*v[2];                              ← One-line macro for torq
```

## 2.12 Fixed variables

This category of variable is the simplest. Its name, **fixed variable**, is rather a contradiction! They are fixed in the sense that they retain the same value throughout the simulation. They are variables in the sense that you can set them to any (reasonable) value. You can also stop the simulation run, reset the value, and then continue the run with the new value.

Since the value is fixed, you set the value of the fixed variable and **AMESim** will leave the variable unchanged until the run stops naturally or is stopped by you. **AMESim** derives many advantages from fixed variables and you are encouraged to use them wherever appropriate.

An example of a submodel with a fixed variable is the constant signal source submodel *CONS0* which has a single output constant value which is a fixed variable.




Internal variables may be fixed variables although it is difficult to see any advantage from this arrangement.

Fixed variables should be used where appropriate instead of basic variables because they help avoid algebraic loops.

## 2.13 Activity variables

The final category of variable is widely used in submodels where energy transfers take place. The activity of an element *i* in a submodel is defined as a temporal integration of the power absolute value

$$A(\tau) = \int_0^{\tau} |P(t)| \cdot dt$$

where *P* is the power in the element. The units are J. The activity represents a quantity of energy that crosses the studied element. This is a different definition from energy because it takes into account the absolute value of power.

An activity variable is always associated with a power variable. It is the user responsibility to assign a value to the power variable in the submodel code. The activity is then calculated by **AMESim** from the power.

Use this kind of variable when you want the activity of your submodel to be calculated, this will allow you to know its index of activity in an **AMESim** model. For more details on the index of activity facility, please refer to the Chapter 8:Activity index in the **AMESim** manual.

An activity variable is defined by a physical type:

- R: dissipation.

- C: capacitance.
- I: inertia.

a physical domain:

- hydraulic,
- mechanical,
- electrical,
- thermal,
- magnetic,
- electric.

and a suffix which is used to generate the name for the power variable associated with the activity. When an activity variable is declared, some extra code is automatically added by **AMESet** at the end of the submodel code.

For more details on this topic, please refer to the Chapter 8:Activity index in the **AMESim** manual.

## 2.14 Scalars and arrays

**AMESim** uses the term array to mean a collection of two or more related quantities regarded as a single object. Scalars are simply single quantities but can be regarded as arrays of dimension one (1).

Many **AMESim** libraries contain no arrays at all. We illustrate with an example from the hydraulic library which contains many submodels with arrays of variables. In the simple submodel of pipe, *HL000*, it is assumed that a single representative value of pressure can be used. Variations in pressure with position within the pipe are ignored.This is referred to as the **lumped parameter** approach. Under many circumstances it is perfectly acceptable. However, if the pipe is long, variations in pressure with position become too important to ignore. Under these circumstances, a **distributed parameter** approach is used in which a series of pressure values are computed.

The submodel *HL020* is a distributive parameter pipe submodel that has an array of 5 internal pressure nodes and an array of 5 internal flow rate nodes. All the pipe submodels *HL0xx*, where *xx* is 10 or above, are distributed parameter submodels with internal variables consisting of arrays of pressure and flow rate.

External variables can also be arrays although this is less common. An obvious case where external array variables are useful is in mechanical submodels where two or three-dimensional motion occurs. In such cases, arrays can be used to specify position coordinates and components of velocity. These will be exchanged between components.

Remember that all external and internal variables are either scalars or arrays.

## 2.15 Complete classification of AMESim variables

**AMESim** variables have a number of classifications:

(i) they are either external or internal;

(ii) they are either scalars or arrays;

(iii) they are one of the following:

- basic variables
- explicit state variables
- implicit state variables
- constraint variables
- duplicate variables (simple or reversed sign)
- one-line macros
- multi-line macros
- fixed variables

(iv) if they are internal variables they may be:

- activity variables

(v) if they are external variables they are either outputs, inputs, inputs with default or input unused.

**AMESim** insists that all variables have titles, units and a dimension. If they are explicit state, implicit state, constraint or fixed variables, they also have special values to be used at the start of the simulation. In the case of a fixed variable, the value will stay the same throughout the simulation. For an implicit state or a constraint variable the value is used as a starting value for an iterative process. For explicit state variables, it is the initial value to be used at the start of the integration.

Four values are associated with this special value of a fixed, explicit state, implicit state or constraint variable:

- a minimum value
- a default value
- a maximum value and
- the actual value set.

When you select a submodel, the actual value is set to the default value for all explicit state, implicit state, constraint and fixed variables. Normally you can change this value in the *Change Parameters* popup. The minimum and maximum values are for guidance only and it is possible to set values outside of this range.

However, a submodel writer can set the minimum, default and maximum values of an explicit state/implicit state/constraint/fixed variable to be the same. **AMESim** takes this as a signal **not to display** the initial value on the *Change Parameters* popup. By this device, the submodel writer can force a particular value always to be used or set the initial value in the initialization section of the submodel code.

## 2.16 Units of external and internal variables

Both external and internal variables have units. If a quantity such as Reynolds number is dimensionless, you must set its units to '*null*'.

The **SI system of units** has won widespread acceptance in the scientific community. In simulation work, use of these units has strong advantages and some disadvantages. The problem is that some SI units are of a highly inappropriate size for general and simulation use. We now consider some examples which illustrates these advantages and disadvantages and describe the **AMESim** solution.

Use of SI units in calculations removes the need for conversion factors. Thus

the flow rate $Q$ in $m^3/s$ from an ideal pump of displacement $D$ $m^3$ rotating at $\omega$ *rad/s* is

$$Q = D\omega$$

but if $Q$ is in *L/s*, $D$ in $cm^3/rev$ and $\omega$ in *rev/min*

$$Q = \frac{D\omega}{60 \times 10^3}$$

**SI Units eliminate conversion factors and in consequence eliminate a common source of error.**

The disadvantage of the use of SI units in simulation is that they often lead to bad scaling of state variables. This is particularly true in hydraulic applications. In hydraulic systems, pressures of the order of $10^7$ *Pa* and flow rates of $10^{-4}$ $m^3/s$ are common but the fluid power engineer is much happier to refer to these as 100 *bar* and 6 *L/min* respectively. Similarly it is extremely inconvenient to measure the spool position in a servo-valve in m. It is better to use mm or a dimensionless fractional spool position. Another bad example is in the field of magnetics where the SI unit of magnetic flux is *Wb* where as most engineers would prefer to express these quantities in $\mu Wb$.

Units such as *bar*, *L/min*, *rev/min* and $\mu Wb$ will be referred to as **Common units**.

The problem is acute if the variable is a state or constraint variable since numerical complexities can arise. The integrator must estimate the error $\varepsilon_i$ in the step for each state variable and constraint variable $y_i$.

The most general error test for the variable is

$$\tau_a + \tau_r |y_i| < \varepsilon_i$$

where $\tau_a$ and $\tau_r$ are error tolerances. There are three common error tests:

1. If $\tau_a$=1 and $\tau_r$=0, the test is called an **absolute error test**.
2. If $\tau_a$=$10^{-16}$ and $\tau_r$=1, the test is called a **relative error test**. We use a small value such as $10^{-16}$ instead of 0 to prevent problems when $y_i$ crosses zero.
3. If $\tau_a$=1 and $\tau_r$=1, the test is called a **mixed error test**. When $|y_i|$ is very large, this is a relative error test and when $|y_i|$ is very small it is an absolute error test.

Normally the mixed or relative test is used. These works extremely well provided the variables are well scaled. By this, we mean that the maximum value of a state/implicit variable in the course of a simulation satisfies

$$10^{\angle 3} < |y_i|$$

Variables that are constant and zero are excluded from this test. This excludes values in *Wb* and $m^3/s$.

By having a different $\tau_a$ and $\tau_r$ for each state/constraint variable $y_i$ and manually adjusting each tolerance value individually, it is normally possible to get good results even if the state/constraint variables are badly scaled. However, this is a tedious operation on a small system and totally impracticable on large systems.

**AMESim** adopts the strategy of encouraging the use of well-scaled variables and using a default mixed error test. This implies the use of non-SI units on occasions. To summarize:

**SI units:** no conversion necessary but sometimes badly scaled.

**Common units:** conversion factors necessary but well scaled.

**To avoid calculations in non-SI units, the AMESet code generation facilities give the option of automatic conversion between SI and common units. Use this facility! This gives the advantages of both SI and common units.**

**AMESim** extensively uses the following common units:

- hydraulic flow rate [*L/min*]
- pressure [*bar*]
- spool position as a fractional value [*null*]
- rotary speed [*rev/min*]
- magnetic flux [μ*Wb*]

## 2.17 Plot access to external and internal variables

It can be useful sometimes for the submodel writer to pass information through variables at ports, and hide some variables from the **AMESim** user to make the submodel clearer. **AMESim**/**AMESet** permits the submodel writer to specify that a variable cannot be plotted by the user. Such a specification is made during the design of the submodel.

## 2.18 Time as a submodel input

Sometimes submodels require time as an input. Usually they can be described **as duty cycle submodels**. They provide an output variable, which is a prescribed function of time. The current value of time is provided by the integration algorithm and is updated as the simulation progresses.

Not all duty cycle submodels require time as an input. One could use another variable on which to base the duty cycle.

## 2.19 Real, integer and text parameters

The size of components has to be defined. The characteristics of duty cycles have to be set. You perform these tasks when you set submodel parameters. **AMESim** sets default parameters when a submodel is selected and you can accept the defaults or change them as you want.

These parameters can be real quantities, integer quantities or text expressions being known as **real parameters**, **integer parameters** and **text parameters** respectively. In computing terms, they are supplied to a submodel as arrays. They are optional and can be omitted if not required.

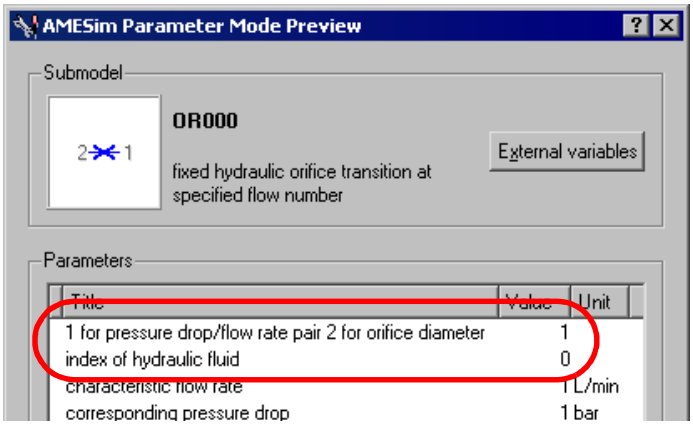
The need for the real parameters is obvious. Integer parameters are normally used for specifying which of several modes is selected. For example, many hydraulic submodels include an orifice. There are two ways that **AMESim** uses to specify the flow characteristics of a submodel:

(i) the user sets an orifice diameter and flow coefficient and these together with the fluid density determine the flow;

(ii) a flow rate and corresponding pressure drop pair are set and used to determine the equivalent diameter.

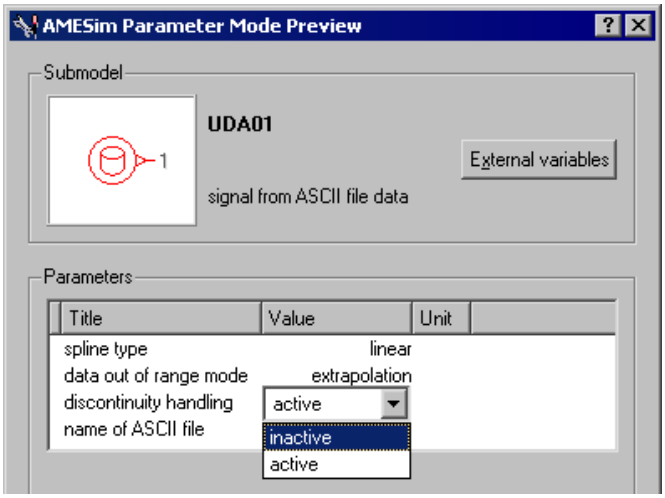
In the orifice submodel *OR000*, an integer parameter is set to 1 to select the flow rate - pressure drop method and 2 to select the diameter method. This is called a **standard** integer parameter. There are two integer parameters in *OR000*.

**Figure 2.11: Two standard integer parameters in OR000.**



The signal source submodel UDA01 uses a different type of integer parameter. This is called an **enumeration integer parameter**. The options are represented by meaningful text strings. UDA01 contains 3 enumeration parameters.

**Figure 2.12: Changing an enumeration integer parameter.**



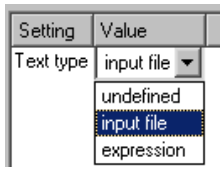

Real and integer parameters have titles associated with them. They also have minimum, default and maximum values. For real parameters, you can set a value outside the range defined by the minimum and maximum value. This is not allowed for integer parameters.

Integer parameters do not have units but **AMESim** insists that all real parameters do have units. If you feel that a real parameter does not have units, set the field to null. If the option of conversion to SI units is used, code will be inserted by the automatic code generation facilities near the end of the initialization part. This code will convert the real parameters from common units to SI units.

Text parameters are collections of one or more character arrays. The most common use is to store the names of files. A more sophisticated use is to store an algebraic expression in terms of one or more variables, which will be evaluated in the submodel. Text parameters have four attributes:

- a title that will be displayed in the *Change parameters* popup,
- a default value for the text parameter
- the current set value of the text parameter and
- a *Text type* field which can take three values.

It is unfortunate that text arrays are stored rather differently in the C language than in Fortran 77. For this reason, text parameters are only allowed in submodels written in C. The form of the initialization and calculation code will now be described.




## 2.20 Initialization and calculation routines

The code of an **AMESim** submodel is written in C or Fortran 77 (F77). In either case there will always be two modules of code (functions if it is written in C or subroutines if in F77). One is called once only at the start of a simulation run and will be referred to as the **initialization routine**. The other will be called many times and will be called the **calculation routine**. In addition, if the submodels uses multi-line macro variables, there will be one function for each multi-line macro.

For a submodel called *NAME*, both routines must be stored in a single source file, which will be *NAME.c* for a C file and *NAME.f* for a F77 file.

In the initialization routine, access is provided to the real, integer and text parameter arrays and to all explicit state, implicit state, constraint and fixed variables. The following activities may be performed in this routine:

- The real and integer parameters may be checked for valid values if you think this is important.
- The set values of explicit state, implicit state, constraint variables and fixed variables can be checked.
- If the minimum, default and maximum values of explicit state, implicit state, constraint or fixed variables are the same, the values cannot be set in the submodel *Change parameters* dialog box. They will be set to the default value when the submodel is selected. You may wish to reset this value in the initialization routine.

- A file specified by a text parameter may be read and the values used in some way.
- If necessary real and integer stores may have their values set. These variables are the subject of the next section.

## 2.21 Real and integer stores

An option available for submodels is to have real and/or integer arrays known as real stores and integer stores. These arrays are accessible in both the initialization and calculation routines. They can be used for whatever purpose you like. The important point is that they retain their values between calls.

Here are some common uses of real stores:

- Used to store expressions calculated in the initialization routine and then used repeatedly in the calculation routine.
- Used to store the final value of an iterative scheme calculated in the calculation routine, which will be used as a starting value the next time the submodel is called.
- Used to store tables of information read from files in the initialization routine and used for interpolation in the calculation routine.

The most common use of an integer store is to store an index number for a particular mode that changes as the simulation progresses. This is extremely important when the submodel features discontinuities. This important topic will now be addressed.

## 2.22 Discontinuities

What is a discontinuity? A good example occurs in modeling a hydraulic actuator or jack. The physical dimensions of the jack body limit the movement of the piston. If the piston is moving within the jack body and reaches the limit of its travel, it must be brought to rest. Often devices incorporate ‘cushion’ so that the piston is brought to rest over a finite distance and in a finite time. If no such device is incorporated, the piston will still be brought to rest over a finite distance and in a finite time due to deformation of the parts involved in the collision.

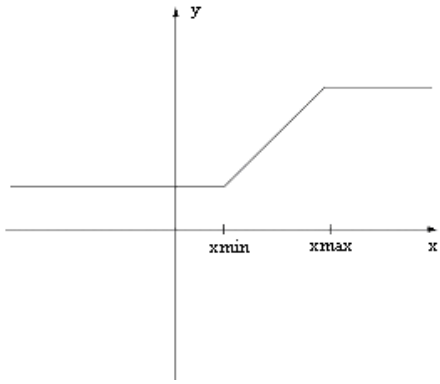
Modeling of this situation is possible and extremely useful for detailed design of hydraulic jacks. However, the transient behavior would be extremely rapid and complex. Use of a hydraulic jack submodel incorporating these features in general hydraulic simulation is unnecessary and might lead to unacceptable run times.

For general purposes, in the hydraulic jack submodel the assumption is made that at the limits of its travel the jack comes instantaneously to rest. This is an example of a **discontinuity**. **A discontinuity is characterized by a physical quantity**

**jumping from one value to another instantaneously**. In this example, the physical quantity is the piston velocity.

Submodels incorporating discontinuities in physical quantities are quite rare. However, there are related phenomena that are more common. A simple example occurs in control systems that include saturation elements. There is an input $x$ and an output $y$. The output is limited to the range $x_{min} \leq y \leq x_{max}$ otherwise $y=x$. A typical example is shown graphically in Figure 2.13. The graph of $y$ against x is **continuous**. However, the **derivative** of $y$ is discontinuous at two points also shown in Figure 2.13. This function has a discontinuity in its first derivative. Other functions have discontinuities in their second or higher derivative. These are not artificially constructed examples but rather examples that do occur in modeling work.

**Figure 2.13: Saturation**

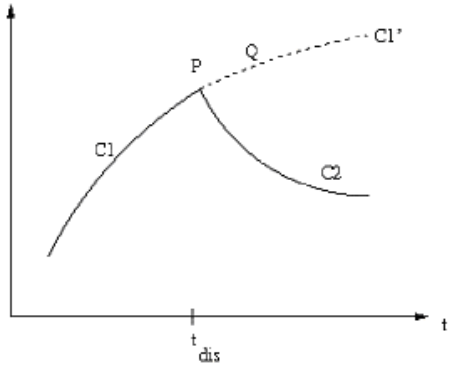



Here are some other examples of discontinuities:

- any form of backlash,
- transition from linear to turbulent characteristics in an orifice,
- frictional stick-slip,
- any form of dead band,
- a valve such as a check valve that has characteristics when open, which are completely different to when closed,
- any form of hysteresis,
- any sort of duty cycle involving steps or ramps,
- submodels which employ linear interpolation for empirical data.

Why is it necessary to stress the occurrence of discontinuities in simulation submodels? The problem lies in the integration algorithms used for solving the o.d.e. and d.a.e. equations that arise in simulation. They are based on integration using methods, which assume that the state variables and some of their derivatives are continuous. If this assumption is not true, special precautions have to be taken at the discontinuity points. This can be illustrated by a simple graph shown in Figure 2.14.

**Figure 2.14: A function with a discontinuous derivative**




The variable has two distinct characteristics resulting in two very different curves C1 and C2. The variable is continuous but the derivative is discontinuous at the point P. The integration methods have no problems when integrating along C1 but at point P problems arise. If no special precautions are taken, as in the following pseudo-code:

```
if(condition)
        use formula for C1
else
        use formula for C2
endif
```

The integrator will drastically reduce its step near the point P in a desperate attempt to meet accuracy requirements. Many integrators will give up with an error message when the step gets too small. Others will have a minimum step size and when this is reached will carry on, even though the accuracy requirements are not met. The first approach leads to frustration and the second can lead to highly inaccurate results.

In the past many simulation packages accepted this situation but now it is almost universally recognized that discontinuities should be handled in a more careful manner. The idea is simple in concept. If the solution is on curve C1 and goes past the point P then the equation for C2 is not used. Instead the equation for C1 is still used so that effectively the curve C1' is employed. This gives rise to a point Q being predicted. The integrator must then realize that a discontinuity point has been passed over and start trying to locate it. This can be done in two ways. Either the integrator tries with a series of smaller steps sizes or some form of interpolation is used. Either way, the point P is located within reasonable accuracy (or even to machine accuracy). After this **the integrator is restarted**, forgetting all information to the left of point P using the smooth curve C2.

This arrangement can be made to work very well but relies on cooperation between the integration algorithm and the submodels. In practice, messages must be sent between them so that submodels detect the discontinuity and inform the integrator.

The integrator informs the submodel when a restart is in progress so that various initialization can be done.

## 2.23 Generation of code skeletons

**AMESim** submodels are written in either Fortran 77 or in C. By constructing new icons and submodels you can greatly extent the capability of **AMESim** and customize it to the needs of your particular application. Writing submodels is a fascinating and rewarding activity but can be difficult and time consuming. To ease the process, the **AMESet** (= AME Submodel editing tool) provides facility to automate part of the code writing process.

In order that **AMESim** can use your submodel, just like standard **AMESim** submodels, you must tell **AMESim** what icons it is associated with, what external and internal variables it has, etc. To do this you effectively fill in a form. The **AMESet** utility provides you with this form and checks your inputs to ensure that they are reasonable and consistent.

When this process is complete, **AMESet** will allow you to assign variable names to external and internal variables and optionally to real and integer parameters. It will then generate a piece of code, the submodel skeleton, in Fortran 77 or C. This will consist of the initialization and calculation functions or subroutines with their declarations. In addition there will be extra functions if the submodel uses multi-line macro variables.

The external and internal variables will be described in comment statements with their titles and units. Similarly the real and integer parameters will be described. The layout will be standardized so that the code will look the same regardless of who wrote the submodel.

Within the code skeleton are at least six insertion points where your enter lines of code for:

- Private code section for own special purposes.
- Initialization function (or subroutine) declaration statements.
- Initialization function (or subroutine) checking statements.
- Initialization function (or subroutine) executable statements.
- Calculation function (or subroutine) declaration statements.
- Calculation function (or subroutine) executable statements.

If in the course of development of the submodel you add or remove external or internal variables or real or integer parameters, by rerunning **AMESet**, the skeleton is regenerated keeping the statements you have added intact. This facility has proved very popular with submodel writers as it removes much of the laborious activity, allowing them to concentrate on the more creative aspects.

# Chapter 3: Getting Started

## 3.1 Introduction

This chapter shows you how to create your own **AMESim** submodels and icons by presenting a series of tutorial examples. However, before attempting to read this chapter and doing the tutorial exercises, you should have experience at using **AMESim** performing simple simulations using the standard **AMESim** submodel libraries. You should also read Chapter 2, which gives a general background on **AMESim** submodels.

The time taken to perform these tutorial exercises varies enormously. They are open-ended in the sense that you can make your own minor modifications to the submodels and to the experiments performed on them but allow at least three hours to do a thorough job.

Creating an **AMESim** submodel involves constructing some code. This can be done in either **Fortran 77** (which will be referred to as F77) or **C**. However, do not allow this to intimidate you. Much of the code can be generated automatically after which you insert a relatively small number of lines of code. Note that there are a lot of sections of code, which have been inserted in this chapter. They are similar to that which is generated by **AMESet** but the code has been shortened slightly by removing some comments.

The final version of each of the submodels described in this chapter is stored in the following directory:

**Using Unix:**

$AME/tutorial/submodels

**Using Windows:**

%AME%\tutorial\submodels

You can of course copy these files into your own submodels area. However, it is better if you generate the submodels and edit them to create the submodel code. Remember that submodels rarely work first time and you will learn far more if you make a few mistakes and correct them. When the author of this manual constructed the submodels described, they certainly did not all work first time!

The development and refinements that can be applied to each submodel is almost unlimited. In particular it is good practice to insert statements checking the values of various parameters and to fill in the description section for each submodel. This

does tend to be very time consuming and is perhaps too tedious for a tutorial exercise. For this reason, at certain points in the exercises it is suggested that you do copy the submodel code from the $AME/tutorial/submodels or %AME%\tutorial\submodels directory and examine it in an editor.

### Submodel name conventions

- **AMESim** submodels have names of **4** to **23** characters comprising uppercase letters and digits.
- In all **AMESim** library submodel names, if there are any digits, the first digit will be in the range **0** to **4**.
- Hence, if you create submodels with names that contain at least one digit and if the first digit is in the range **5** to **9**, there will be no name clashes with existing standard submodels.

## 3.2 A rack and pinion submodel with calculation of angular position

The rack and pinion submodel *RACK00* is available in the **AMESim** mechanical standard library. The first port requires a linear velocity in *m/s* as an input and computes a force in *N* as output. The second port requires a torque in *Nm* as an input and computes a rotary velocity in *rev/min* as output. The displacement of the rack in *mm* is calculated as an internal **explicit state** variable. Other information required is the radius of the pinion in *mm*.

**Figure 3.1: The external variables of RACK00**

A simple modification can be made to *RACK00* to produce *RACK50*, which will calculate the angular position of the pinion.

### Step 1: First you use AMESet to load and examine the standard *RACK00*.

1. Start AMESet as follows:

**Using Unix:**

Talk to your system administrator who will show you how to set up your working environment so that you get access to AMESet. To start AMESet, in a suitable window change to the directory where you wish to work (*tutorial* for instance) and type:

*AMESet*

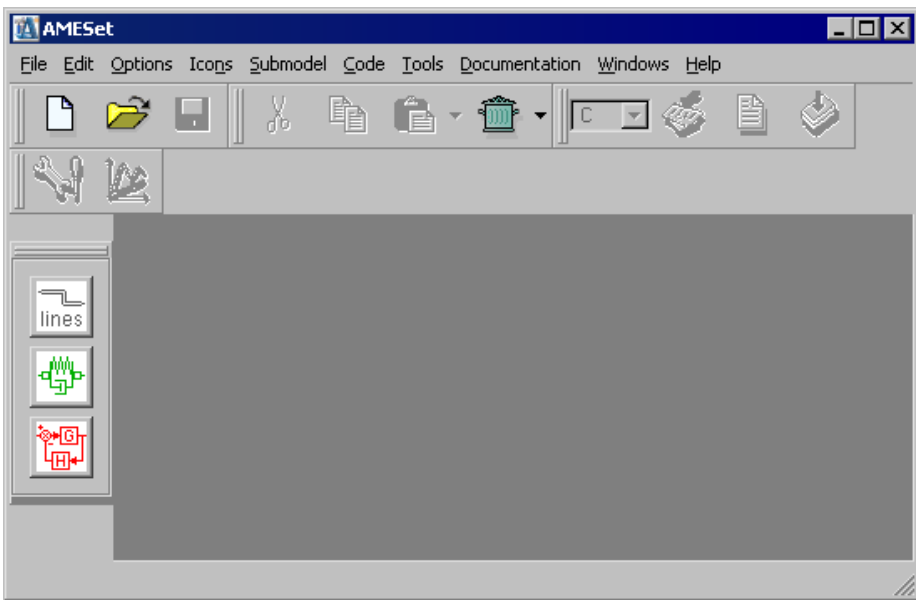
**Using Windows:**

Do one of the following:

- Select *AMESet* from the menu **Program ▶ Imagine ▶ AMESet** produced by the **Start** button, or
- Double click on the AMESet icon on your desktop, or
- Type *AMESet* in a MS DOS Command window from the directory where you wish to work (*tutorial* for instance).

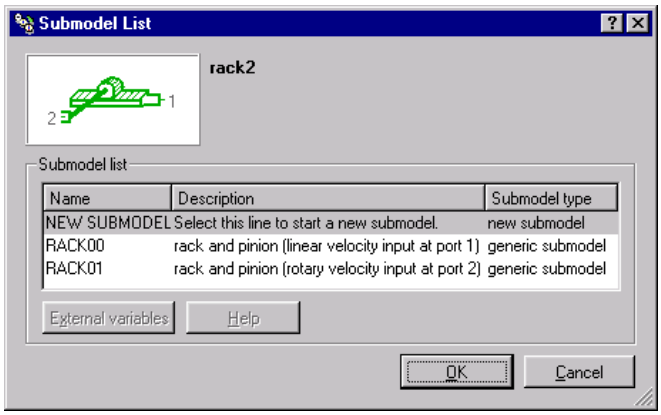
The display shown in  will appear. It has been deliberately made similar to AMESim but there are small differences in the display and AMESet performs very different functions. The main display area, which in AMESim is used to present the system sketch, will be used to display details of submodels and icons.

**Figure 3.2: The AMESet display**



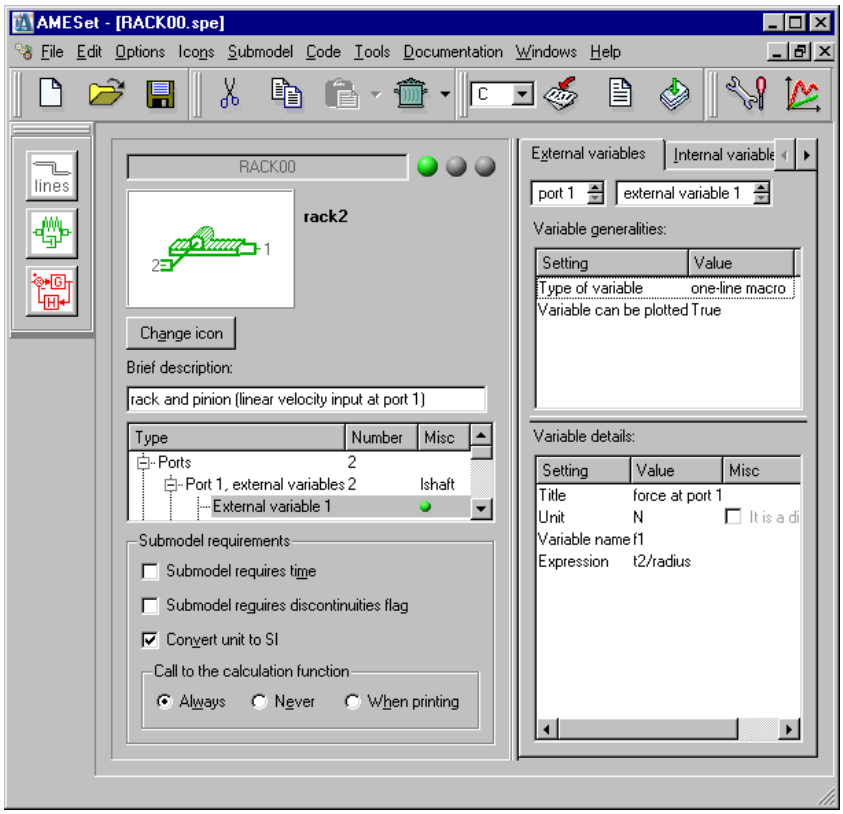
1. At the left hand side of the **AMESet** display are the *Categories* buttons. Select the *Mechanical* category and then click on the standard rack and pinion icon. The dialog box below will appear.

**Figure 3.3: Submodels associated with the icon rack2**



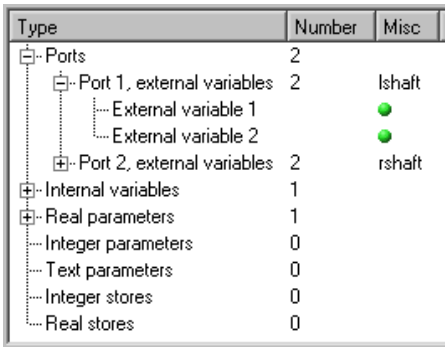

Select the submodel *RACK00* in the list and click on *OK*. Figure 3.4 shows the new display.

**Figure 3.4: RACK00 loaded into AMESet**



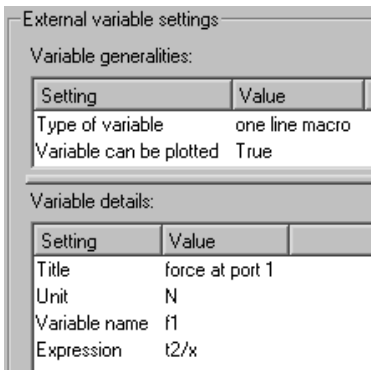
2. Examine the details of the existing submodel. First concentrate on the tree structure on the left shown below:

**Figure 3.5: Ports, variables and parameters for RACK00**



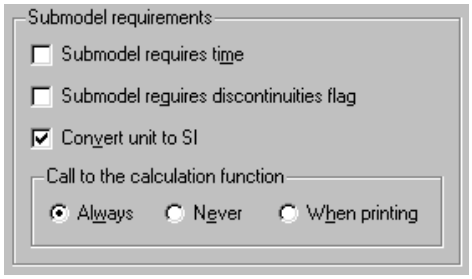

Currently *Port 1, external variables* and *External variable 1* is selected and in the right hand side of the display details of this external variable are displayed.

**Figure 3.6: External variable**




3. Examine other details as follows:
   - Select port 1 *External variable 2*.
   - Expand *Port 2, external variables* and select in turn each of the two external variables.
   - Expand *Internal variables* and select the single internal variable
   - Expand *Real parameters* and select the single real parameter.
   - Note the status of the *Submodel requirements* at the bottom left:

**Figure 3.7: Submodel requirements**




4. Just in case you have made any accidental changes, do **File ▶ Close**.

### Step 1: The next stage is to plan carefully what you are going to do

1. You will use the standard rack and pinion icon, which has 2 ports.
2. You will base the new submodel on *RACK00* which has four external variables and one internal variable.
3. *RACK50* will have the same external variables, but two internal variables. The additional one being the **angular position** of the pinion. You are going to edit the submodel *RACK00* and alter it slightly in order to introduce this extra internal variable.
4. You will then save it as *RACK50*.

   According to this plan, *RACK50* will have the specifications listed below. They are the same as *RACK00* except the one in bold:

- There are 2 ports:

| Field | Port 1 variable 1 | Port 1 variable 2 | Port 2 variable 1 | Port 2 variable 2 |
|---|---|---|---|---|
| Type | one line macro | basic variable input | one line macro | basic variable input |
| Title | force at port 1 | linear velocity at port 1 | rotary velocity at port 2 | torque at port 2 |
| Unit | N | m/s | rev/min | Nm |
| Name | f1 | v1 | w2 | t2 |
| Expression | t2/radius | - | v1/radius | - |
| Dimension | - | 1 | - | 1 |

- There are 2 internal variables:

| Field | Internal variable 1 | Internal variable 2 |
|---|---|---|
| Type | explicit state | **basic variable** |
| Can be plotted | - | **True** |
| Title | displacement of the rack | **angular position** |
| Unit | mm | **degree** |
| Name | x | **theta** |
| Derivative name | dx | **-** |
| Dimension | 1 | **1** |
| Min value | 0 | **-** |
| Default value | 0 | **-** |
| Max value | 0 | **-** |

- There is 1 real parameters:

| Field | Parameter 1 |
|---|---|
| Title | radius of the pinion |
| Unit | mm |
| Variable name | x |
| Min. | -100000 |
| Default | 10 |
| Max. | 100000 |

- The submodel does not generate discontinuities.
- The submodel does not require time.
- The submodel does require SI unit conversion.

### Step 2: Create the new submodel

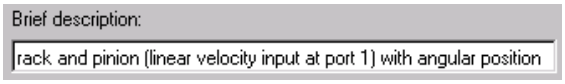
For this simple submodel the planning is complete and you can use **AMESet** to create a specification of the submodel and generate a code skeleton. It is good idea to create a special folder or directory called *tutorial* and do all the exercises in this directory.

Note that for the rest of the tutorial exercises, you should save all your submodels in the same area in which you are now working (*tutorial* directory). The process of generating code for new submodels is largely a matter of filling forms. Here you

are going to use the settings of the already existing submodel *RACK00* and alter them to get our own submodel you will call *RACK50*:

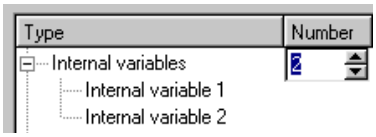
1. If necessary, reload RACK00 as you did in Step 1.
2. In the brief description field, type in the text shown below. The description field contains text, which will be displayed when submodels are selected in **AMESim**.

**Figure 3.8: The brief description for the rack and pinion submodel**



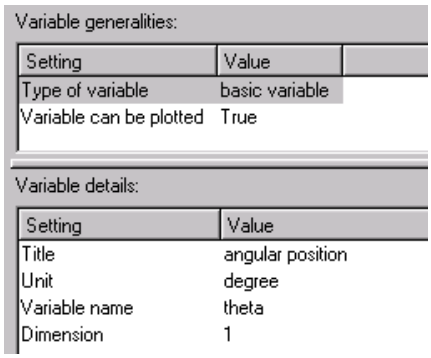

3. Below is a table in which you will find the list of the existing variables, parameters and stores. Select the item *Internal variables* and click on the column *Number*. The current number of internal variable is **1**: set it as **2**.

**Figure 3.9: Adjusting the numer of internal variables**




4. Select the item *Internal variable 2* and assign it the features shown in Figure 3.10 : The new internal variable characteristics.

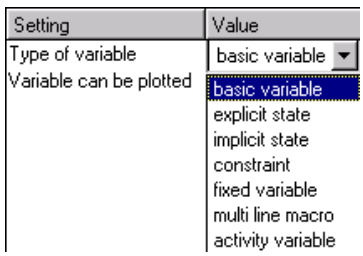
**Figure 3.10: The new internal variable characteristics**




At this point a few words of explanation are needed:

- The variable type is chosen in a list of possible types:

**Figure 3.11: Setting the type of variable**



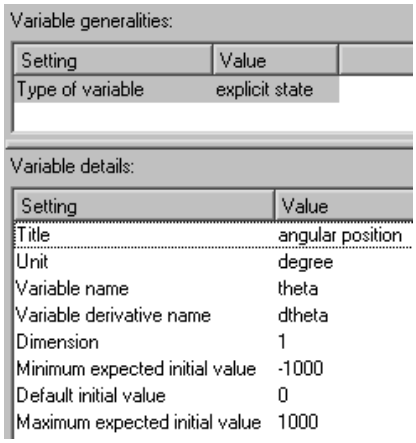
You select *basic variable* because the angular position can be obtained directly from the position of the rack and the radius of the pinion. The angular position is explicitly defined by:

$$theta = \frac{x}{radius}$$

*x* is the linear position of the rack and *radius* is the radius of the pinion.

- Another way of determining theta would be to use the fact that the derivative of *theta* is *omega*. The angle *theta* could then be calculated from the angular velocity *omega* by the **AMESim** integrator. This would involve setting up the internal variable as follows:

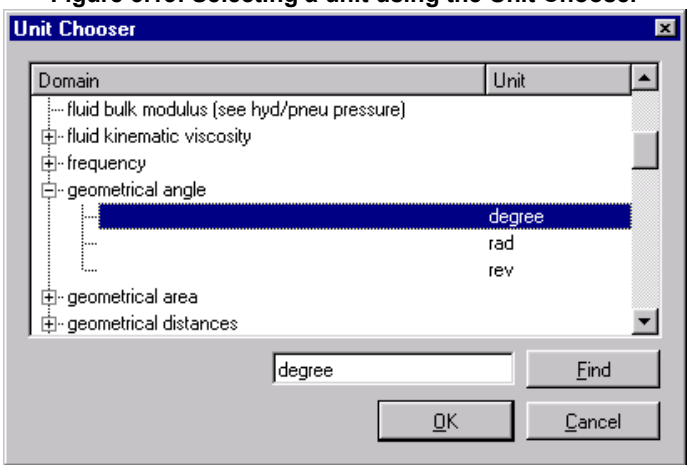
**Figure 3.12: Internal variable**




However, this would be inefficient because you would be using 2 state variables when only one is needed. This is the reason why we define *theta* as a basic variable.

- The unit can be directly typed in or it can be chosen in the list below. This list is obtained by clicking on the button ..., to the right of the *Value* field:

**Figure 3.13: Selecting a unit using the Unit Chooser**



- **AMESet** can create code in Fortran 77 (F77) or in C. Since F77 is the most restrictive of these languages in terms of variable names, **AMESet** uses the F77 name restrictions on variable names. Hence names must
  - be of 12 characters or less (the strict standard says 6 but normally 12 is accepted);
  - consist of either alphabetical characters or digits;
  - start with a letter.

**Note:** There are some further restrictions due to reserved C and F77 keywords such as **if**, **else**, **for**, **call** etc. If you enter a wrong keyword, you are informed with the red light in the upper right side of the interface, or with an error message.

  - The dimension must be left at 1. Dimensions greater than 1 indicate an array of variables. This feature is useful on occasions but its use is not common.

5. You can also get a preview of the *Change Parameters* and *Variable List* dialog boxes you would get in **AMESim**. Click on the buttons and to get the previews shown in Figure 3.14 and Figure 3.15 respectively:

**Figure 3.14: Parameter Mode Preview**

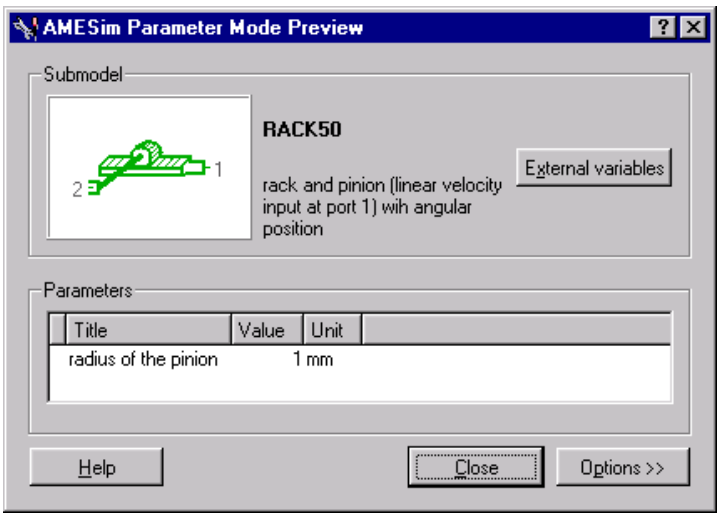
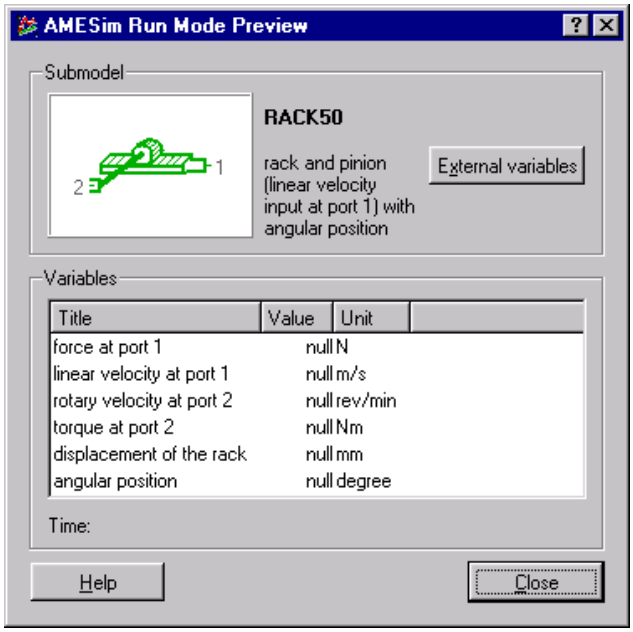


**Figure 3.15: Run Mode Preview**




.

6. Select the programming language you want **AMESet** to use for creating the submodel code (either C or Fortran).

7. Generate the submodel code by clicking on , then click on in order to edit this code. Below is an example of the code generated in C. The next section (3.3 Comments on the code generated by AMESet) gives more details on the content of the following code.

   Please note that the code is edited in the **AMESet** fallback editor, which is the current default editor. If you wish to use another editor, please refer to the paragraph 5.4.3 Options menu, AMESet preferences in the Editors section.

**In C:**

```
/* Submodel RACK50 skeleton created by AME Submodel editing utility
   jeu. 27. mars 09:16:00 2003 */
#include <math.h>
#include <stdio.h>
#include <stdlib.h>
#include "ameutils.h"
/*****************************************************************************
TITLE : RACK50
-----------------------------------------------------------------------------
DESCRIPTION :
   This submodel of a rack and pinion converts a linear velocity v1
   in m/s (port 1) into an angular velocity w2 in rev/min (port2) and
   a torque t2 in Nm (port 2) into a linear force in N (port 1) f1.

        w2 = v1 / radius        (S.I. units)
        f1 = t2 / radius        (S.I. units)

   where radius is the transformation ratio set by the user which corresponds
   to the primitive radius of the pinion.

   A rack displacement in mm (x) is calculated by integrating the linear
   velocity (v1).
-----------------------------------------------------------------------------
USAGE :
-----------------------------------------------------------------------------
PARAMETER SETTINGS :
   The transformation ratio (radius) must be different from zero! However,
   a negative value will be accepted. This can be used to reverse the
   sign of the rotary motion.
-----------------------------------------------------------------------------
DATE OF CREATION/AUTHOR : 26/02/1999 R.RHOTE-VANEY
-----------------------------------------------------------------------------
SOURCE :
    IMAGINE Roanne (42)
   5, rue Brison
   42300 ROANNE           tel: (33).04.77.23.60.30
   FRANCE                 fax: (33).04.77.23.60.31
*****************************************************************************/
/* >>>>>>>>>>>>Insert Private Code Here. */
/* <<<<<<<<<<<<End of Private Code. */

/* There is 1 real parameter:
    rp[0] = radius
        radius of the pinion [mm -> m]
*/

/* There are 0 integer parameters:

*/
```

```
/* There are 0 text parameters:

*/

#ifdef _NO_PROTO
void rack50in_(n, rp, x)
   int *n;
   double rp[1];
   double *x;
#else
void rack50in_(int *n, double rp[1], double *x)
#endif
{
   int error = 0;
/* >>>>>>>>>>>>Extra Initialization Function Declarations Here. */
/* <<<<<<<<<<<<End of Extra Initialization declarations. */
   double radius;

   radius     = rp[0];

/*
   If necessary, check values of the following:

   rp[0..0]
   *x
*/

/* >>>>>>>>>>>>Initialization Function Check Statements. */

   if(radius == 0.0)
   {
      fprintf(stderr, "/nPinion radius cannot be = 0./n");
      error = 2;
   }

/* <<<<<<<<<<<<End of Initialization Check Statements. */
   if(error == 1)
    {
      fprintf(stderr, "\nWarning in RACK50 instance %d.\n", *n);
   }
   else if(error == 2)
   {
 fprintf(stderr, "\nFatal error in RACK50 instance %d.\n", *n);
      fprintf(stderr, "Terminating the program.\n");
      AmeExit(1);
   }
/* Common -> SI Conversions. */
   rp[0]    *= 1.00000000000000e-003;
   radius     = rp[0];
```

```
/* >>>>>>>>>>>>Initialization Function Executable Statements. */

/* <<<<<<<<<<<<End of Initialization Executable Statements. */
}

/*  There are 2 ports.

      Port number 1 has 2 variables:

         Variable number 1 `f1' function expression is:

            't2/radius'
            force at port 1  [N]
        Variable number 2 `v1' variable scalar input
            linear velocity at port 1  [m/s]
      Port number 2 has 2 variables:
        Variable number 1 `w2' function expression is:
            'v1/radius'
            rotary velocity at port 2  [rev/min]
        Variable number 2 `t2' variable scalar input
            torque at port 2  [Nm]
   */
/*  There are 2 internal variables.

     Variable number 1 (x) explicit state scalar derivative `dx'
         displacement of the rack  [mm -> m]
     Variable number 2 (theta) variable scalar
         angular position  [degree -> rad]
   */

#ifdef _NO_PROTO
void rack50_(n, v1, t2, x, dx, theta, rp)
   int *n;
   double *v1;
   double *t2;
   double *x;
   double *dx;
   double *theta;
   double rp[1];
#else
void rack50_(int *n, double *v1, double *t2, double *x, double *dx
      , double *theta, double rp[1])
#endif
{
   *theta      = ??;
*/
 int logi;
/* >>>>>>>>>>>>Extra Calculation Function Declarations Here. */
/* <<<<<<<<<<<<End of Extra Calculation declarations. */
   int loop;
   double radius;
```

```
   radius     = rp[0];
  /* Common -> SI units conversions. */

   *x        *= 1.00000000000000e-003;

/*
   Set all submodel outputs below:

   *dx         = ??;

/* >>>>>>>>>>>>Calculation Function Executable Statements. */

   *dx = *v1;

/* <<<<<<<<<<<<End of Calculation Executable Statements. */

/* SI -> Common units conversions. */

   *x        /= 1.00000000000000e-003;
   *dx       /= 1.00000000000000e-003;
   *theta    /= 1.74532925199433e-002;
}
```

1. Alter the code as follows in the *Calculation Function Executable Statements*:

**In C:**

```
/* >>>>>>>>>>>>Calculation Function Executable Statements. */

   *dx = *v1;
   *theta = *x/radius;

 /* <<<<<<<<<<<<End of Calculation Executable Statements. */
```

**In F77:**

```
C>>>>>>>>>>>>Calculation Function Executable Statements.

      dx = v1
      theta = x/radius

C<<<<<<<<<<<<End of Calculation Executable Statements.
```

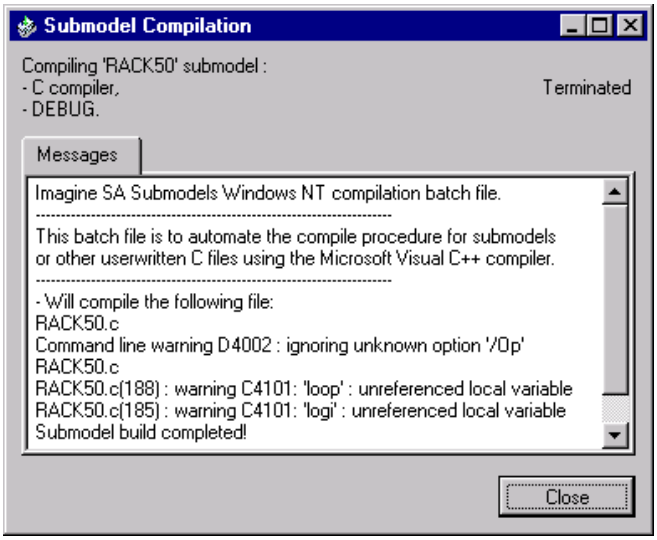
As the automatic SI unit conversion is applied, you do not have to take care of the units:

- *v1* is in m/s,
- *theta* is in degree,
- *x* and *radius* are in mm

These variables are all converted to SI units before the executable statements so that the formula giving *theta* does not require any conversion coefficients. At the end of the executable statements the variables are converted back to their original units.

1. Next close the editor (**File ▶ Close** for the fallback editor) and compile the code by clicking on the button . A dialog box similar to the one below will appear indicating if the code is compiled properly:

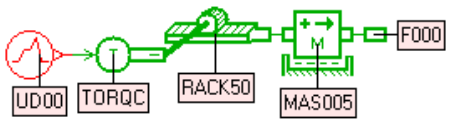
**Figure 3.16: Compiling RACK50**




## Step 1: Test your new submodel.

1. Start **AMESim** and build the small model below in order to test your new submodel:

**Figure 3.17: The new submodel in AMESim**



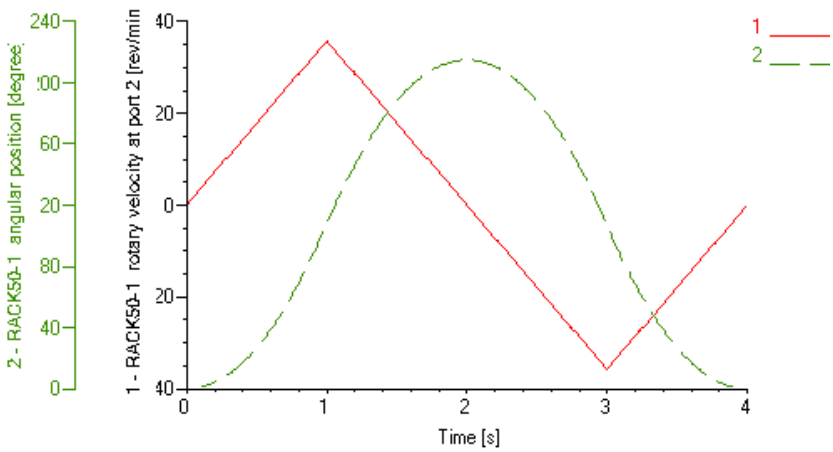

A piece wise linear torque profile is applied to the rack and the angular position will respond to this.

2. In *Submodel* mode, select the submodels and in *Parameter* mode assign them the following non-default parameters:

| Submodel | Title | Value |
|---|---|---|
| UD00 | output at start of stage 1 [null] | -15 |
| | output at end of stage 1 [null] | -15 |
| | duration of stage 1 [s] | 1 |
| | output at start of stage 2 [null] | 15 |
| | output at end of stage 2 [null] | 15 |
| | duration of stage 2 [s] | 2 |
| | output at start of stage 3 [null] | -15 |
| | output at end of stage 3 [null] | -15 |
| | duration of stage 1 [s] | 1 |
| RACK50 | radius of the pinion [mm] | 200 |

3. Run a simulation for 4 seconds with a communication interval of 0.01 second and plot the angular position of the pinion and its velocity. You should get the following curves:

**Figure 3.18: Angular position and velocity of the pinion**



# 3.3 Comments on the code generated by AMESet

## Functions defined in the submodel code

The first thing to notice is that there are **2** Fortran subroutines or **2** C functions:

- The first is for **initialization** and is called once at the beginning of the simulation.
- The second is for **calculations** and is called many times during the simulation.

## Calculation accuracy

All arithmetic is performed to double precision accuracy.

> **In F77:**
>
> One consequence of this is that in F77 code you should always put real constants in double precision form i.e. 0.39d0 rather than 0.39 or 0.39e0.

## User reserved places in submodel code

There are six places in the code where you are invited to insert your own lines. These start with <<<< and end with >>>> characters. These insertion points are described below in Fortran:

1. C >>>>>>>>>>>>>Insert Private Code Here.

   `C <<<<<<<<<<<<End of Private Code.`

   The private parts section can be used for various purposes. You could for instance write a function or subroutine, which is called by your submodel.

2. `C >>>>>>>>>>>>>Extra Initialization Function Declarations Here.`

   `C <<<<<<<<<<<<End of Extra Initialization declarations.`

   Here you are invited to make extra variable declarations you which to use in the initialization subroutine or function.

3. `C  If necessary, check values of the following:`

   `C  rp(1..1)`

   `C  x`

   `C >>>>>>>>>>>>>Initialization Function Check Statements.`

   `C <<<<<<<<<<<<End of Initialization Check Statements.`

   Here you have the option to make checks on variable and parameters. This section is preceded by comments that suggest the things that you might like to check. In this case it is the starting value of the state variable (the linear displacement of the rack) and the value of the real parameter (the radius of the pin-

ion).

4. `C >>>>>>>>>>>>Initialization Function Executable Statements.`

   `C <<<<<<<<<<<<End of Initialization Executable Statements.`

   Here you insert statements that assign variables. This will become clearer in later examples.

5. `C >>>>>>>>>>>>Extra Calculation Function Declarations Here.`

   `C <<<<<<<<<<<<End of Extra Calculation declarations.`

   Here you can declare extra variables and functions for the calculation subroutine or function.

6. 
```
C     Set all submodel outputs below:
C     dx       = ??
C     theta    = ??
C >>>>>>>>>>>>Calculation Function Executable Statements.
C <<<<<<<<<<<<End of Calculation Executable Statements.
```

   Here assignments are made for the outputs of the submodel. **AMESet** tells which variables have to be set.

## Submodel description

Note the lines of code which are near the beginning of the file, they are similar to the following ones which are in Fortran:

```
C
*****************************************************************
*
C TITLE :
C
C ---------------------------------------------------------------
--
C DESCRIPTION :
C
C ---------------------------------------------------------------
--
C USAGE :
C
C ---------------------------------------------------------------
--
C PARAMETER SETTINGS :
C
C ---------------------------------------------------------------
--
C REVISIONS :
C
C
*****************************************************************
```

It is intended that you:

- Modify this template if it is already filled with information on the submodel from which you create the current submodel. This is the case for *RACK50* which was made from *RACK00*.

- Complete this template if it is empty as shown above. This happens when you create a submodel without starting from an existing one.

These lines give a description of the submodel you are currently constructing.

## AMESim integrator

It is worth mentioning a small point, which does sometimes cause confusion to beginners:

| **It is not the job of the submodel to do the integration.** |
|---|

There is a central integration algorithm for doing this. Thus you do not make an assignment in the calculation code for the state variable (theta or *theta) using your favorite integration method. Instead you must define the derivative of the state variable (omega or *omega) and from this derivative, this is the **AMESim** integrator which calculates the state.

## C language specific features

If you ask **AMESet** to generate your submodel code in C, you must be aware of conventions which are specific to this programming language:

- **AMESim** generates calls to submodels without consideration as to whether they are written in F77 or C. In practice this means that all variables on the argument list will be referenced as **pointers**. If variables that are used in assignment statements are on the argument list, they will have a '*' in front of them. Thus you have:

  **dx = *v1;*

  **theta = *x/radius;*

  rather than

  *dx = v1;*

  *theta = x/radius;*

- Some Unix versions of C conform to the ANSI standard and use full function prototypes. Others do not. You will notice constructions of the type

  *#ifdef _NO_PROTO*

  *some statements*

  *#else*

  *some different statements*

  *#endif*

  The first set of statements is for versions of C which do not accept full function prototypes and the second for those that do. If compilation is performed with a

  *-D_NO_PROTO*

option, the first set of statements will be compiled otherwise the second set will be compiled.

## Compilation flags for Fortran below Unix

For F77 users under a Unix environment the following information may be of interest.

When compiling, the following set of options is useful:

*f77 -c -g -C -u ...*

- -g option prepares the code for use within a debugger.
- -C enables array bound checking.
- -u flags undeclared variables as errors.

## Check statements

At this point, if you were to continue developing the submodel, you would **check** the value of some variables and warn the user or even stop the simulation run if the user had set completely unsatisfactory values. For the time being it is suggested that you look at the code in the *$AME/submodels* (or *%AME%/submodels*) area to see how **check statements** are inserted rather than actually do the operations yourself.

You can look at the source code of any submodel (called NAME for instance) in the **AMESim** system area. You will find that this code contains a **description** as well as **check statements** that are very carefully filled. The easiest way is to load the appropriate file into your preferred editor:

**Using Unix:**

*$AME/tutorial/submodels/*NAME.*f or*

*$AME/tutorial/submodels/*NAME.*c or*

*$AME/submodels/*NAME.*c*

**Using Windows:**

*%AME%\tutorial\submodels*NAME.*f or*

*%AME%\tutorial\submodels*NAME.*c or*

*%AME%\submodels*NAME.*c*

You have read only access to these files and you can print them if you want. **The check statements test the value of some variables such as real parameters, explicit state initial values, fixed variables etc. If it is an unacceptable value, the program may be stopped**. Note how the statements are placed in a special checking section of the initialization routines between lines labeled:

**In F77:**

```
C >>>>>>>>>>>>>Initialization Function Check Statements.
C <<<<<<<<<<<<End of Initialization Check Statements.
```

or

**In C:**

```
/* >>>>>>>>>>>>>Initialization Function Check Statements. */
/* <<<<<<<<<<<<End of Initialization Check Statements. */
```

In the current submodel (*RACK50*) the check statements come from *RACK00* and can be updated.

A special variable named **error** is declared for you and initialized to **0**:

- If you want the program to be stopped when an unacceptable value is found, you must set the local variable *error* to **2**.
- If it is just a warning, set *error* to **1**.

After the section for checking, the value is examined, a message printed and if necessary the program is terminated.

## Stopping a simulation from a submodel

Note that in the C code you do not use the function *exit* to stop the simulation but rather the function *AmeExit*. Similarly in Fortran you do not use *stop* but rather the subroutine *famexit*. You could use *exit* or *stop* but the alternatives provided enable **AMESim** to terminate in a rather more graceful manner. This is very important when your **AMESim** executable is interfaced with some other code (such as with the Simulink interface).

We will repeat the following request several times in the manual:

- If you use C, do not use the function *exit* (or *abort*). Use *AmeExit(1)* instead.
- If you use F77, do not use the subroutine *stop*. Use *call famexit(1)* instead.

Note there is one integer argument to these functions. You normally set this to 1. The value 0 indicates a normal exit and any other value an abnormal exit (i.e. on detecting an error).

## Files associated with a submodel

Note that for each submodel you create (called NAME for instance) there are three files associated with it:

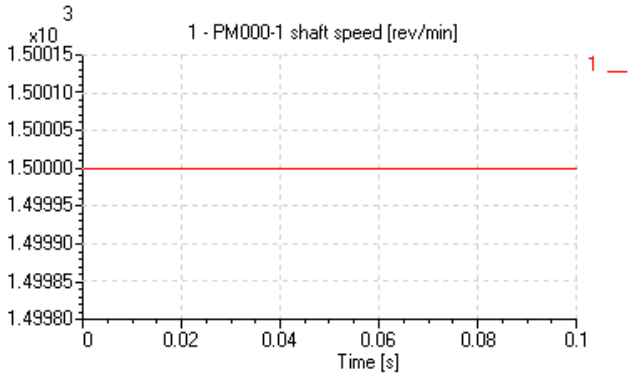
- The source file NAME.f or NAME.c.
- The specification file NAME.spe.
- The compiled version of the source NAME.o (or NAME.obj).

# 3.4 Prime mover with start up characteristics

## 3.4.1 Introduction

The simplest prime mover submodel of the *Mechanical* library is *PM000* which is a constant speed source. There is only one external variable which is a fixed variable with title *shaft speed* and units *rev/min*. A typical graph of the shaft speed using the default parameters is shown below:

**Figure 3.19: The constant speed prime mover**




It would be interesting to develop a submodel, which gave the start up characteristics of the prime mover. Denoting the speed of the prime mover at time *t* by $\omega$, a simple model of the start up characteristics is:

$$\omega = \varpi(1 - exp(-t/\tau))$$

where $\varpi$ is the final speed of the prime mover in *rev/min* and $\tau$ is a time constant in seconds. You could have taken the angular speed in *rad/s* so that everything was in SI units, but the use of *rev/min* does not introduce any unpleasant conversion factors.

The formula assumes the prime mover starts from rest at time $t = 0$. It might be useful to be able to modify this formula so that the prime mover could be started after some time delay. If it starts at time $t = t_{start}$, the equation becomes

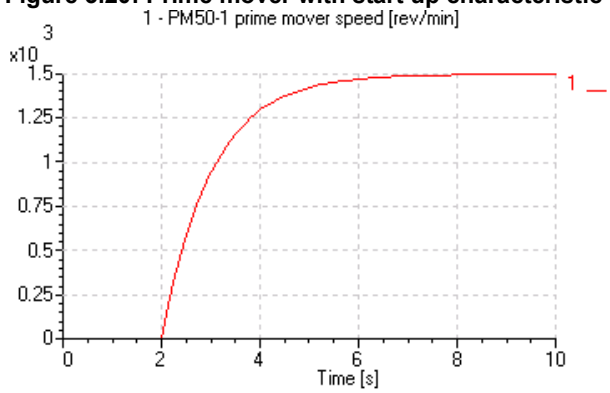
$$\upsilon = \varpi\left\{1 \angle \exp\left(\frac{\angle(t \angle t_{start})}{\tau}\right)\right\}$$

for $t \geq t_{start}$ and $\omega = 0$ otherwise.

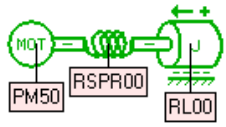
There will still be a single variable but it will be of type *basic variable* instead of *fixed variable*. In addition, there will be three real parameters with the following titles and units:

- *final speed [rev/min]*
- *time constant [s]*
- *startup time [s]*

**Figure 3.20: Prime mover with start up characteristic**




A typical graph of ω against time is shown in Figure 3.19. It is clear that ω is a continuous function of time but its derivative is not (discontinuity at time $t = 2\ s$).




If the prime mover were connected to a rotary spring as shown, the discontinuity would be transferred to the spring submodel *RSPR00*. The angular twist θ calculated by the spring submodel is a state variable and ω would be used in defining its derivative. Hence θ would have a discontinuity in its second derivative. This is a relatively mild discontinuity and it is marginal as to whether special precautions should be taken for this. Generally speaking:

- it is essential to take special precautions if states or their first derivatives are discontinuous;
- if there is a discontinuity in the third or higher derivative of a state, no special precautions are necessary;
- for a discontinuous second derivative of a state it is wise, but not normally essential, to take special precautions. For this example, you will try both approaches.

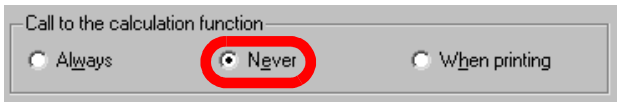
## 3.4.2 Submodel with no discontinuity handling

You will first create a prime mover submodel without any discontinuity handling:

1. Start **AMESet**, select the prime mover icon from the *Mechanical* library and choose the submodel *PM000* in the submodel list.

   Note the following information about this submodel.

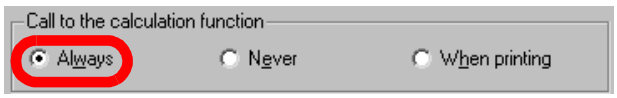
   **Figure 3.21: Calculation function Never called**

   *PM000* is a very simple submodel. It is so simple that there is no need for a calculation function at all. Ticking the *Never* radio button ensures **AMESim** will never attempt to call the calculation function.

2. Since you DO want **AMESim** to call our calculation function, tick the *Always* radio button.

   **Figure 3.22: You do want the calculation function called**

   Note there is a third possibility: call the calculation function only *When printing*. This is useful when there are only information only variables.

3. Set the number of real parameters to 3 and set their titles, units, variable names and minimum, default and maximum values as suggested in the following table:

| Field | Parameter 1 | Parameter 2 | Parameter 3 |
|---|---|---|---|
| Title | final speed | time constant | startup time |
| Unit | rev/min | s | s |
| Variable name | omegaf | tau | tstart |
| Min. | -5000 | 1e-6 | -1e6 |
| Default | 1500 | 1 | 0 |
| Max. | 5000 | 1e3 | 1e6 |

Below is what you should have for the first real parameter:

**Figure 3.23: First real parameter**

Parameter details:

| Setting | Value |
|---|---|
| Title | final speed |
| Unit | rev/min |
| Variable name | omegaf |
| Minimum expected fixed value | -5000 |
| Default fixed value | 1500 |
| Maximum expected fixed value | 5000 |

4. Specify that there is one external variable on port 1 with the characteristics shown in Figure 3.23.

**Figure 3.24: The external variable of PM50**

External variables | Internal variables | Real

port 1 | external variable 1

External variable settings

Variable generalities:

| Setting | Value |
|---|---|
| Type of variable | basic variable |
| Input/output status | output |
| Variable can be plotted | True |

Variable details:

| Setting | Value |
|---|---|
| Title | prime mover speed |
| Unit | rev/min |
| Variable name | omega |
| Dimension | 1 |

5. For the submodel brief description use (see Figure 3.24):

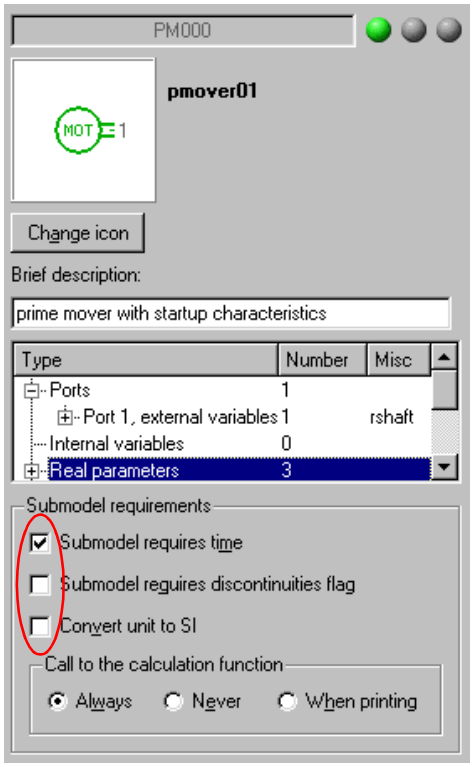
   *'prime mover with start up characteristics'*

6. There is one important difference between *PM50* and *RACK50*. *PM50* requires access to time. This can be achieved by clicking on the check box labeled *Submodel requires time*.

7. As we will not deal with discontinuities for the time being, ensure that the check box *Submodel requires discontinuity flag* is not ticked.

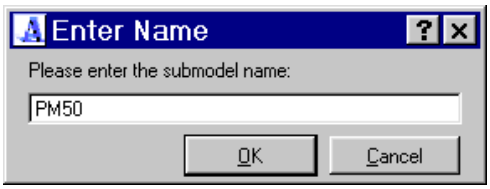
8. In this example **it is definitely not worth converting to SI units** so ensure that the check box *Convert to SI Units* is not ticked.

**Figure 3.25: Submodel requirements**




9. Now select **File** from the menu bar and then **Save**. The dialog box below should appear and you can then type the name of your submodel.

**Figure 3.26: Type the name of your submodel**




10. Generate the code skeleton by clicking on and edit the generated code with .

In the calculation routine **omega** must be defined. This involves inserting the following lines of code:

**In F77:**

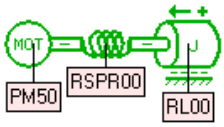
```
if (t .ge. tstart) then
   omega = omegaf*(1- exp(-(t - tstart)/tau))
else
   omega = 0.0
endif
```

**In C:**

```
if (*t >= tstart)
{
   *omega = omegaf*(1- exp(-(*t - tstart)/tau));
}
else
{
   *omega = 0.0;
}
```

1. Compile the submodel by clicking on and then test it with a suitable system in **AMESim**. The following test system is satisfactory:

**Figure 3.27: Test system for PM50**

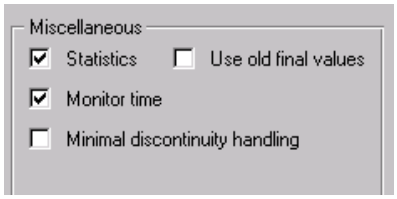



Note that while you are doing this you can exit **AMESet** or leave it running. Try it with various final speeds, time constants and startup times. You will probably find its performance is satisfactory despite the discontinuity. However, ignoring discontinuities like this can create problems and often leads to longer simulation runs. Enable run S*tatistics* from the *Run parameters* (see Figure 3.26) and perform a run making a note of:

- The time for the simulation.
- The maximum step size used.
- The number of function evaluations.

The latter is the number of times each submodel is called.

**Figure 3.28: Enable statistics**



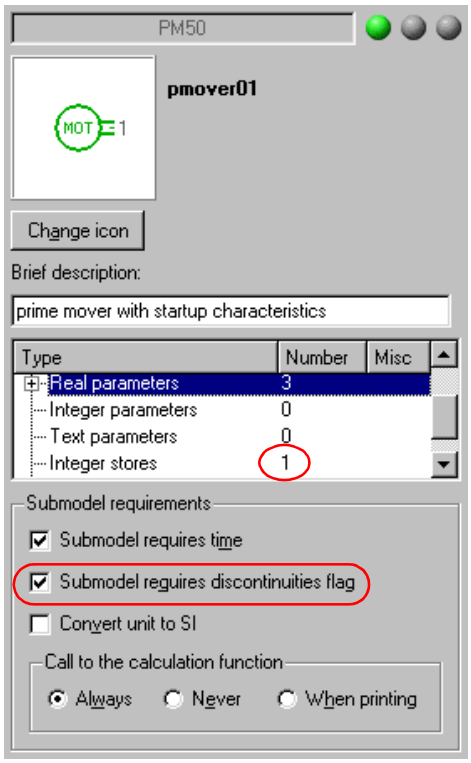

## 3.4.3 Submodel with discontinuity handling

### Modification of the submodel specification

To modify *PM50* to handle the discontinuity properly, restart **AMESet** if necessary and select the prime mover. *PM50* will appear as an existing submodel and you must select it to read in the current specification. There are two changes to be made to the specification:

1. Tick the check box *Submodel requires discontinuity flag*.
2. Set the number of *Integer stores* to 1.

**Figure 3.29: Change submodel requirements**




**When you have done this, save this new version as *PM51***. You can then generate *F77* or *C* code without any further modification.

**In F77:**

```
      subroutine pm51(n, omega, rp, ic, flag, t)
      integer n, ic(1)
      double precision rp(3), omega
      double precision t,tau, tstart
      integer flag
      logical logi
      logical disimp
      external disloc, disimp
      external distim
C >>>>>>>>>>>>Extra Calculation Function Declarations Here.
C <<<<<<<<<<<<End of Extra Calculation declarations.
      omegaf = rp(1)
      tstart = rp(2)
      tau = rp(3)
      C Set all submodel outputs below:
      C omega = ??

C >>>>>>>>>>>>Calculation Function Executable Statements.
      if (t .ge. tstart) then
      omega = omegaf*(1- exp(-(t - tstart)/tau))
      else
      omega = 0.0
      endif
C <<<<<<<<<<<<End of Calculation Executable Statements.
      end
```

**In C:**

```
#ifdef _NO_PROTO
void pm51_(n, omega, rp, ic, flag, t)
    int *n;
    double *omega;
    double rp[3];
    int ic[1];
    int *flag;
    double *t;
#else
void pm50_(int *n, double *omega, double rp[3], int ic[1],
            int *flag , double *t)
#endif
{
    int logi;
/* >>>>>>>>>>>>Extra Calculation Function Declarations Here. */
/* <<<<<<<<<<<<End of Extra Calculation declarations. */
    double omegaf, tstart, tau;
    omegaf = rp[0];
    tstart = rp[1];
    tau = rp[2];
/*
Set all submodel outputs here:
*omega = ??;
*/
/* >>>>>>>>>>>>Calculation Function Executable Statements. */
    if(*t >= tstart)
    {
            *omega = omegaf*(1 - exp(-(*t - tstart)/tau));
    }
    else
    {
            *omega = 0.0;
    }
/* <<<<<<<<<<<<End of Calculation Executable Statements. */
}
```

**Note:**

- **AMESet** has kept your lines of executable code provided you put them in the approved place.
- An extra variable called **flag** has appeared on the argument list. This is the discontinuity variable and plays an extremely important role in the handling of discontinuities.
- A variable named **logi** has been declared which is of type *int* in C code and *logical* in the Fortran code.
- In the Fortran code subroutines named **disloc** and **distim** are declared on external statements and the logical function **disimp** is also declared on an external statement. These utilities will be called to handle discontinuities as they occur.

These functions are actually also declared in the C code but the declaration are in the header file *ameutils.h*. Strangely in C they are named **disloc_**, **distim_** and **disimp_**. There is a good reason for this. By adding the underscore, the same utility *name_* can be called as *name* from F77 code and *name_* from C code.

- The array **ic** dimensioned at 1 has appeared on the arguments list. This is the integer store and in the present submodel it will be used to record the current state of the prime mover i.e. whether the speed is a constant zero before the start up time, or is rising with time.
- The integer variable **loop** is introduced to deal with cases where some external or internal variable is an array and is used as a 'do' or 'for' loop parameter.

## Modification of the submodel code

The modifications you must make to the code are as follows:

**In F77:**

```
      subroutine pm51(n, omega, rp, ic, flag, t)
      integer n, ic(1)
      double precision rp(3), omega
      double precision t,tau
      integer flag
      logical logi
      logical disimp
      external disloc, disimp
      external distim
C >>>>>>>>>>>>Extra Calculation Function Declarations Here.
C <<<<<<<<<<<<End of Extra Calculation declarations.
      omegaf = rp(1)
      tstart = rp(2)
      tau = rp(3)


C Set all submodel outputs below:
C omega = ??


C >>>>>>>>>>>>Calculation Function Executable Statements.
      if(flag .eq. 0)then
         if(t .ge. tstart)then
```

```
C Prime mover has started.
            ic(1) = 1
         else
C Prime mover has not started.
            ic(1) = 0
         endif
      endif
      if(ic(1) .eq. 1)then
C Prime mover has started.
         omega = omegaf * (1 - exp(-(t-tstart)/tau))
      else

C Prime mover has not started.
         omega = 0
C Register discontinuity at time tstart
         call distim(tstart)
      endif
C <<<<<<<<<<<<End of Calculation Executable Statements.
      end
```

**In C:**

```
#ifdef _NO_PROTO
void pm51_(n, omega, rp, ic, flag, t)
   int *n;
   double *omega;
   double rp[3];
   int ic[1];
   int *flag;
   double *t;
#else
void pm50_(int *n, double *omega, double rp[3], int ic[1], int *flag
 , double *t)
#endif
{
   int logi;
/* >>>>>>>>>>>>Extra Calculation Function Declarations Here. */
/* <<<<<<<<<<<<End of Extra Calculation declarations. */
```

```
   double omegaf, tstart, tau;
   omegaf = rp[0];
   tstart = rp[1];
   tau = rp[2];
/*
 Set all submodel outputs here:
*omega = ??;
*/
/* >>>>>>>>>>>>Calculation Function Executable Statements. */
   if(*flag == 0)
   {
      /* Initialization call. Set the value of ic[0]. */
      if(*t >= tstart)
      {
         /* Prime mover has started. */
         ic[0] = 1;
      }
      else
      {
         /* Prime mover has not started. */
         ic[0] = 0;
      }
   }

   if(ic[0] == 1)
   {
      *omega = omegaf*(1 - exp(-(*t - tstart)/tau));
   }
   else
   {
      *omega = 0.0;
      /* Register discontinuity at time tstart. */
      distim_(&tstart);
   }
/* <<<<<<<<<<<<End of Calculation Executable Statements. */
}
```

At this point a few words of explanation are needed:

- Calls are made to the calculation routine with integer **flag** set to a variety of values. The value indicates the purpose of the call. The only special value you need worry about is **flag = 0**. This is a call to the routine for the purpose of initialization. At the start of each run, the first call to each submodel which has a discontinuity will have **flag = 0**. If any discontinuity occurs during a run, immediately after the discontinuity is located there will be a further call to each submodel with **flag = 0**. This allows the submodel to perform any initialization.

- For the current submodel, **ic(1)** (in F77) or **ic[0]** (in C) is set to **0** if the prime mover is in the pre-start up phase or **1** otherwise.
- There are now two sections of code corresponding to each of the two values of the **ic** state indicator. For each call to the submodel, only one section of code will be visited.
- A switch from one section of code to the other corresponds to a discontinuity. In this case it is possible to switch from the pre-start up to the post-start up phase but impossible to switch in the other direction.
- The Fortran subroutine **distim** (or the C function **distim_**) is used to register discontinuities which occur at a known time.
- Note that great care is needed to ensure complete consistency. Thus if the following statements had been used:

**In F77:**

```
      if(t .gt. tstart)then
         ic(1) = 1
      endif
```

**instead of**

```
      if(t .ge. tstart)then
         ic(1) = 1
      endif
```

**In C:**

```
      if(*t > tstart)
      {
         ic[0] = 1;
      }
```

**instead of**

```
      if(*t >= tstart)
      {
         ic[0] = 1;
      }
```

there could have been a major conflict. A discontinuity could have been located at time **tstart** and a restart organized. The **ic(1)** or **ic[0]** variable would then have been set to 0 and another discontinuity located at time **tstart** followed by another restart. What would happen after this is rather unpredictable.

To summarize:

Discontinuities involve changing from one regime, mode or state to another. Each regime has its own set of continuous equations. It is of the greatest impor-

tance that the code for detecting a change of regime should be totally consistent with the code for setting the regime. In the present example you are using:

| ic(1) | condition for regime | condition for leaving regime |
|---|---|---|
| 0 | t .lt. tstart | t .ge. tstart |
| 1 | t .ge. tstart | t .lt. tstart |

or:

| ic[0] | condition for regime | condition for leaving regime |
|---|---|---|
| 0 | t < tstart | t >= tstart |
| 1 | t >= tstart | t < tstart |

However, note that in this example, since time does not go backwards, you do not need to test for leaving the region corresponding to **ic(1)=1** (in F77) or **ic[0]=1** (in C).

### Submodel test

Retest the submodel with the same system as before (Figure 3.25). Remove the old submodel *PM50* by selecting the new prime mover *PM51* in *Submodel* mode. After this, collect statistics for the run (see Figure 3.26) with the modified submodel. You should find that the run:

- is faster,
- has fewer function evaluations and
- uses a bigger maximum step size.

The cost is a slightly more complex submodel, which must be coded very precisely. You can examine the files *PM51.f* and *PM51.c* files in the *$AME/tutorial/submodels* or *%AME%\tutorial\submodels* areas (the same as with *RACK50*).

## 3.5 Square wave submodel

This is the last exercise, which deals specifically with discontinuities. Clearly a square wave is a discontinuous function. Here is some simple code for the square wave:

**In F77:**

```
      cycles = t/c(1)
      if (cycles/2*2 .eq. cycles) then
C At minimum value.
      output = minv
      else
C At maximum value.
      output = maxv
      endif
```

**In C:**

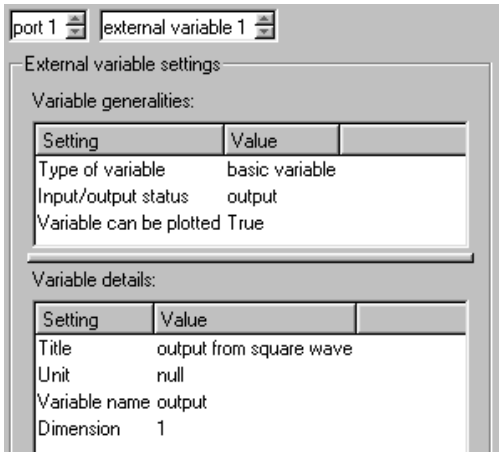
```
      cycles = (int)(*t/c[0]);
      if (cycles/2*2 == cycles)
      {
         /* At minimum value. */
         *output = minv;
      }
      else
      {
         /* At maximum value. */
         *output = maxv;
      }
```

You are going to create your own square wave submodel using the code above and the icon shown.

This icon can be found in the *Signal, Control and Observers* category. The following points give indications for constructing this submodel which you will call *SQ50*.

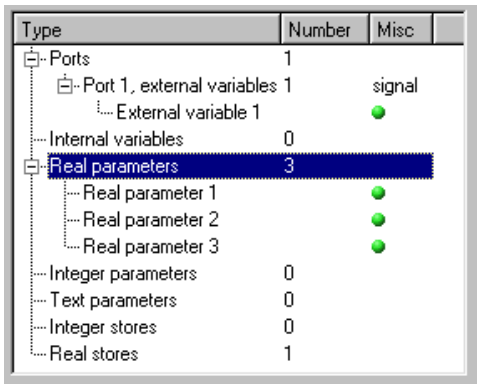
- The submodel SQ50 has a single external variable, which we have referred to as output:

**Figure 3.30: The external variable for SQ50**




- The frequency in *Hz* is a *real parameter*, which can be denoted by **f**:

**Figure 3.31: Frequency in Hz**




- The variables **minv** and **maxv** are also *real parameters* representing the minimum and maximum values of the square wave. This gives three *real parameters*:

  *frequency of square wave[Hz]*

  *minimum value[null]*

  *maximum value[null]*

- The variable **cycles** is local to the calculation routine of the submodel and must be declared in the declaration section of the calculation routine as follows:

```
C >>>>>>>>>>>>Extra Calculation Function Declarations Here.
      integer cycles
C <<<<<<<<<<<<End of Extra Calculation declarations.
```

or

```
/* >>>>>>>>>>>>Extra Calculation Function Declarations Here. */
   int cycles;
/* <<<<<<<<<<<<End of Extra Calculation declarations. */
```

It is used to count the number of semi-periods that have been covered.

- The variable **c(1)** or **c[0]** is a *real store* element and will be set to half of the period. It will be set in the initialization code section for executable statements as follows:

```
C >>>>>>>>>>>>Initialization Function Executable Statements.
      c(1) = 0.5d0/f
C <<<<<<<<<<<<End of Initialization Executable Statements.
```

or

```
/* >>>>>>>>>>>>Initialization Function Executable Statements. */
   c[0] = 0.5/f;
/* <<<<<<<<<<<<End of Initialization Executable Statements. */
```

- Note that the device:

```
if (cycles/2*2 .eq. cycles) then
```

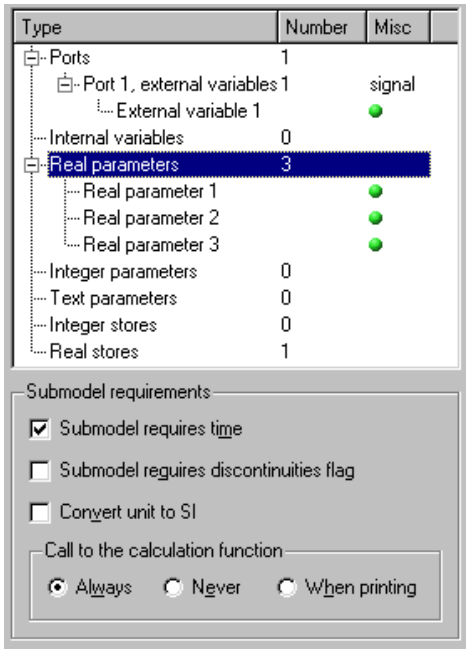
or

```
if (cycles/2*2 == cycles)
```

is used to determine whether **cycles** is even or odd. This is quite an old trick but for those who have not seen it before, a short explanation is required. Suppose **cycles** = 5. It follows that **cycles**/2 is 2 (as the rule is to round towards 0 for integer division), **cycles**/2*2 is 4 and the test is false. If on the other hand **cycles** = 6, **cycles**/2 is 3, **cycles**/2*2 is 6 and the test is true. This gives a very simple test for an integer being even.

You now have enough information to introduce *SQ50* using **AMESet**. Associate it with the existing icon shown in Figure 3.26. Do not forget to declare the submodel as requiring time and that there is 1 real store. At the moment it does not need access to the discontinuity variable flag and so is declared as not having discontinuities:

**Figure 3.32: Variables, parameters, stores and submodel requirements**




Test the submodel with the systems shown in Figure 3.30.

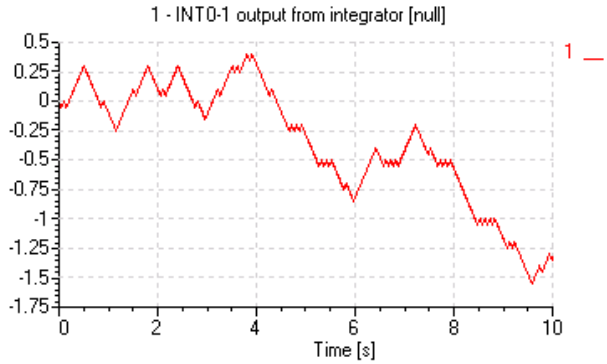
**Figure 3.33: Test systesm for SQ50**

- For the first system, there are no state variables. **AMESim** will limit the step size to the communication interval unless this is larger than the declared maximum step size. *SQ50* can do nothing other than return the correct value. If you reduce the communication interval to value of, say, one tenth of the period of the square wave, the square wave will be represented very well in the plot.
- For the second system, there are severe problems. If you set the following values:

| Submodel | Title | Value |
|---|---|---|
| SQW0 | frequency of square wave [Hz] | 10 |
| | minimum value [null] | -1 |
| | maximum values [null] | 1 |

it is very easy to show that the output from the integrator should be a wave of triangular form with minimum value -0.05 and maximum value 0. With a communication interval of 0.1 *second* and the default maximum step size, a typical output from the integrator is shown in Figure 3.31.

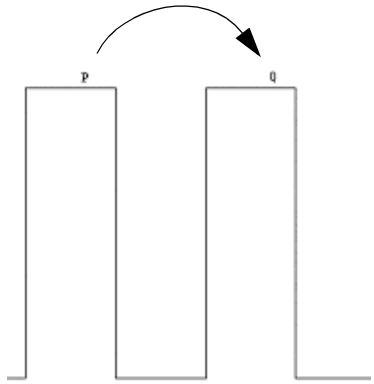
**Figure 3.34: Bad results for first version of SQ50**




This is clearly unsatisfactory. What is happening is that since the integrator is seeing a constant value from the square wave, the step size is going to grow rapidly. Sometimes it may find that output from the square wave switches to a completely different value. In these circumstances the step will be rejected on accuracy grounds and be repeated with a smaller step size until the accuracy requirement is meet.

Alternatively the step size may give the situation shown in Figure 3.32. Here *P* corresponds to the time at the previous step and *Q* to the new step. The accuracy requirement is satisfied and integrator will probably increase the step size even further.

**Figure 3.35: AMESim takes a big step**

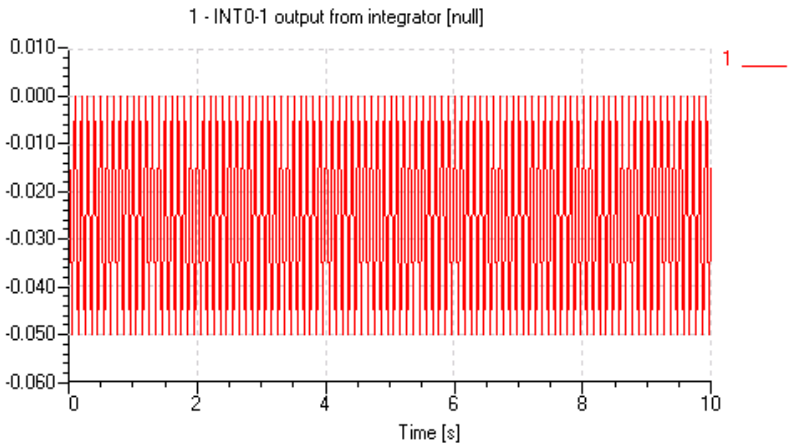



Since there is now a state variable, reducing the *Communication interval* from the *Run Parameters* dialog box will achieve little. Reducing the *Maximum time step* to, say, one tenth of the period (0.01) will be more successful and you should get results similar to what is shown in Figure 3.33. However, if the simulation is run for, say, 1000 seconds inaccuracies become apparent. Try this with the *Communication interval* increased to 1 second to avoid over large result files.

- Repeat these experiments with the standard square wave submodel *SQW0*. You can do this by removing *SQ50* and replace it by *SQW0*. Make sure you reset the

*Maximum time step* back to its default (1.0e30), you will get the following results:

**Figure 3.36: Results using SQ50**




How does this submodel achieve so much more accuracy? The answer is simply that it employs the principles of locating discontinuities and ensuring the integrator always integrates continuous functions.

Here are some simple modifications you can employ for *SQ50* to make it perform as well as *SQW0*:

1. Start **AMESet** and select *SQ50*.
2. Alter the submodel specification as follows:
   - Set the number of real stores as 2.
   - Set the number of integer stores as 1.
   - Declare the submodel as having discontinuities.
3. Regenerate the code.
4. Change the calculation routine as shown below.
5. Run a simulation with **AMESim** using *SQ50* instead of *SQW0* and check you get proper results (as in Figure 3.33).

**In F77:**

```
      if (flag .eq. 0) then
C The integration has just started or restarted.
         cycles = t/c(1)
C Determine time of next discontinuity.
         c(2) = (cycles + 1)*c(1)
C Determine which value will be used.
         if (cycles/2*2 .eq. cycles) then
C At minimum value.
            ic(1) = 0
         else
C At maximum value.
            ic(1) = 1
         endif
      endif
C Set output according current state.
      if (ic(1) .eq. 0) then
         output = minv
      else
         output = maxv
      endif
C Check for discontinuity.
      call distim(c(2))
```

**In C:**

```
if(*flag == 0)
{
   /* The integration has just started or restarted */
   cycles = (int)(*t/c[0]);
   /* Determine time of next discontinuity */
   c[1] = (cycles +1)*c[0];
   /* Determine which value will be used */
   if (cycles/2*2 == cycles)
   {
      /* At minimum value. */
      ic[0] = 0;
   }
   else
   {
      /* At maximum value. */
      ic[0] = 1;
   }
}
if (ic[0] == 0 )
{
   *output = minv;
}
else
{
   *output = maxv;
}
/* Check for discontinuity */
distim_(&c[1]);
```

# Chapter 4: Advanced examples

## 4.1 Introduction

In this chapter you are introduced to:

- more discontinuity facilities,
- more on duplicate variables,
- macro and activity variables,
- in addition you are given advice on how to avoid algebraic loops.

We assume that most C programmers can understand Fortran 77 but probably the reverse is not true. Hence we present the code of most examples in Fortran 77 but, if there are subtle differences, the C code is also presented.

However, note that all submodels in the **AMESim** libraries are written in C. A powerful facility in **AMESet** is that you can load a standard **AMESim** submodel, modify it in some way and save it locally under a different name. To use this facility you have to work in C.

We also illustrate the sort process used in **AMESim** by showing code generated by **AMESim**. This is always in C.

## 4.2 Bouncing ball

The object of this exercise is to construct some submodels, which have a number of interesting discontinuities. This is one feature that must be treated carefully in **AMESim** and you will probably require a little practice before you master the process. Another subject of interest is the *activity* variables that we will also introduce in this chapter.

In Chapter 3 there were two examples with a discontinuity which occurred at a known time. In practice **AMESim** goes past the discontinuity and then effectively interpolates back to find the values of the state and implicit variables at the known discontinuity time. In other situations it is more difficult because although it is easy to detect that **AMESim** has gone past the discontinuity, the time at which the discontinuity occurred is not known by the submodel and hence **distim** cannot be used.

It is worth stressing at this stage the following points:

- **The AMESim integrator does not detect discontinuities.**
- **It is the responsibility of AMESim submodels to detect discontinuities and tell the AMESim integrator about them.**
- **When a discontinuity has been registered by a submodel with the integrator, the integrator will locate the discontinuity.**

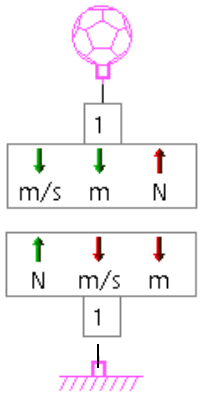
Imagine a ball released from rest above a floor. The ball will bounce off the floor until it comes to rest. This is a very familiar situation and it is a rich source of modeling details. It is very instructive for modelers of all levels.

During the motion, there are two distinct stages:

1. the ball is moving freely under gravity;
2. the ball is in contact with the floor.

The equations governing the motion of the ball in these two stages are quite different. The times at which the ball comes in contact with the floor and leaves the floor are clearly discontinuity points. We do not know in advance (unless we solved the equations analytically) the time at which the discontinuities occur.

You will construct two icons similar to those shown. One icon represents the ball and the other the floor. This figure also shows that each icon has one port and shows the external variables for each of the two submodels that will be constructed. For the ball submodel there are two output variables corresponding to $y$ and $v$ and one input variable corresponding to $F$. The situation is reversed for the floor submodel.




All these variables have a direction associated with them. With the **AMESim** sign convention positive quantities are in the direction of the arrow. This means a positive velocity $v$ and displacement $y$ will be measured downwards and gravity will assist them. A positive force $F$ will oppose them.

It follows that the governing equations are:

$$\frac{\delta y}{\delta t} = v$$

$$\frac{\delta v}{\delta t} = g \angle \frac{F}{m}$$

where $m$ *is* the mass of the ball. The force $F$ excludes the force due to gravity and will be taken to be zero when the ball is free of the floor and non-zero when in contact with the floor. We are making assumptions but this is always the case in a

modeling situation. In particular we are ignoring air resistance, which is reasonable, since the speeds involved will be relatively small.

See the standard **AMESim** icon ports in Chapter 12: Facilities Available In Sketch Mode of the **AMESim** manual. This convention is important and it is bad practice to introduce new types of port without good reason.

> **Bearing in mind the units on the ports, we recommend you use linear shaft (lshaft) ports.**

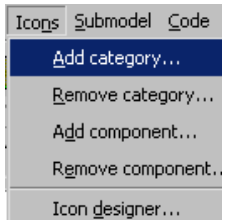
You will construct a submodel *BL50* for the ball and *FL50* for the floor. However, since none of the standard icons are suitable, you must construct two new ones.

There are **AMESim** categories which store the icons needed for libraries supplied with the **AMESim** package. You are not allowed to add you own icons to these. However, you can create one or more of your own categories in which you can store your own component icons. You may have already created categories and component icons for supercomponents using **AMESim**. The process is exactly the same in **AMESet**, but the method of starting the process is different.

## 4.2.1 Creating category and component icons in AMESet

In **AMESet** the processes are started from the **Icons** menu in the menu bar. The steps to follow are:

**Step 1: Decide if you need to create a new category icon. If you already have a suitable category, go to step 3.**




**Step 2: Create a new category icon.**

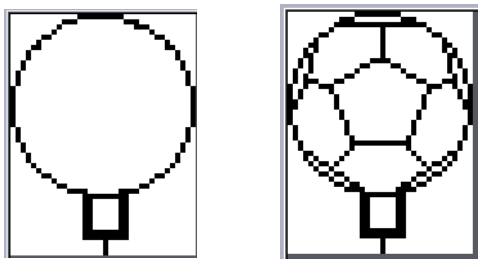
1. **Icons▶Add category ....**
2. Create the new category icon. If necessary refer to section 11.4.7 Icons menu of the **AMESim** manual.

If you have no idea what the icon should look like, here is a suggestion.

**Step 3: Create an icon for the ball with a single linear shaft port.**

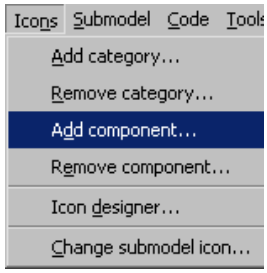
1. **Icons▶Add component icon**
2. Create the ball icon. If necessary refer to section 11.4.7 Icons menu of the **AMESim** manual. Do not forget to add the style of the single linear shaft port and to specify its position. Here are two suggestions for different levels of artistic competence.

**Figure 4.37: Examples of ball icons**

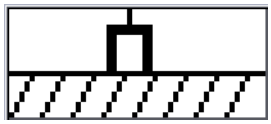


**Step 4: Create an icon for the floor with a single shaft port.**

1. **Icons ▶ Add component....**

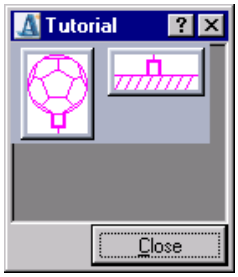



2. Create the floor icon. Do not forget to add the style of the single linear shaft port and to specify its position. Here is a suggestion.



**Step 5: Verify that the category exists and the two icons are in it.**

**Step 6: Set suitable colors for the new category using Options ▶ Color preferences.**




## 4.2.2 Creating the submodel BL50 for the bouncing ball

How will the submodel work? We have already decided that there are three external variables associated with the single port. We will work in SI units and give the variables obvious titles. To summarize we have as our port 1 variables:

1. explicit state: *'velocity of ball'[m/s]*
2. explicit state: *'displacement of ball'[m]*
3. basic variable (input): *'external force on ball'[N]*

Note the order of the variables. The port of the icon was set to type **lshaft**. Normally one of the variables on such a port is a force in *N*. The others will be one of the following combinations:

| Variable 1 | Variable 2 | Variable 3 |
|---|---|---|
| velocity [m/s] | - | - |
| velocity [m/s] | displacement [m] | - |
| velocity [m/s] | displacement [m] | acceleration [m/s/s] |

If a new submodel with linear shaft port is going to connect to an existing **AMESim** model with an lshaft port, it is important to adhere to this order. Thus velocity comes before displacement.

Are there any real parameters? Clearly the mass of the ball, *m*, must be a real parameter. The acceleration due the gravity, *g*, could be another. However, the value is unlikely to be set to anything other than 9.81. Hence for this exercise we will stick to one real parameter with title, units, minimum, default and maximum values as follows:

4. *'mass of ball'[kg]* 1.0e-3 0.1 0.5

Does the submodel generate discontinuities? The answer is that it does not. Discontinuities occur in the force generated by the floor and they will be dealt with there.

**Step 1: Run AMESet, select the ball icon from its category and select a new submodel.**

**Step 2: Set the number of external variables on port 1 as 3 and define the 3 variables.**

Suggested variable fields are:

| Fields | Port 1 variable 1 | Port 1 variable 2 | Port 1 variable 3 |
|---|---|---|---|
| Variable type | explicit states | explicit state | basic variable (input) |
| Title | velocity of ball | displacement of ball | external force |
| Unit | m/s | m | N |
| Variable name | v | y | fext |
| Derivative name | vdot | ydot | - |
| Minimum | -1000 | -10 | - |
| Default | 0 | 0 | - |
| Maximum | 1000 | 10 | - |

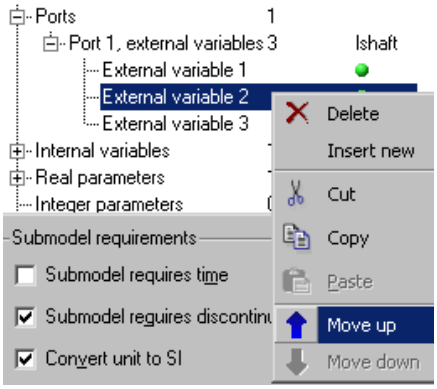
Note that these variables are in the correct order. We must ask a question:

**What happens if I get the order wrong?**

Sooner or later you will do this and it is easy to correct!

1. First **AMESet** will impose the rule **outputs** before **inputs** before **inputs with default**. You have no choice.
2. In the current example it is possible to get variables the wrong way round. To correct this, click on the appropriate *external variable* with the right button and select the item *Move down* or *Move up*.

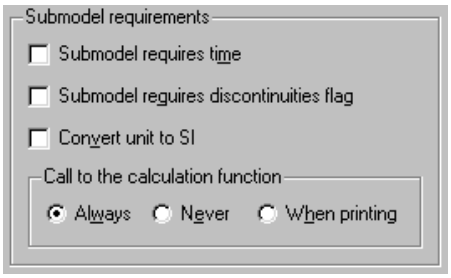
**Figure 4.38: Changing the order of external variables.**




## Step 3: Set the number of real parameters to 1. Define it as follows

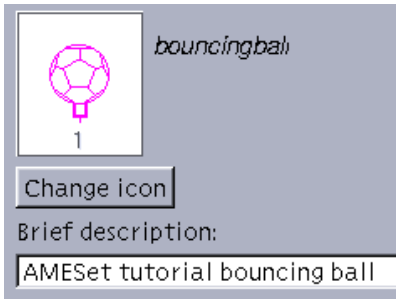
| Field | Value |
|---|---|
| Title | mass of ball |
| Unit | kg |
| Variable name | mass |
| Min. | 0.001 |
| Default | 1 |
| Max. | 10 |

The definition of the variables and parameters is now complete. You do not need time or the discontinuity flag. You are already using SI units and so the status of the *Convert to SI units* check box is irrelevant. Hence you just have to unselect it and you are ready to save the submodel.



**Step 4: Set the submodel brief description as shown below:**

**Figure 4.39: Brief description.**




**Step 5: Save the submodel as *BL50*.**

**Step 6: Do a preview of *Parameter* mode, *Simulation* mode and *External variables* as a check that all has been done well.**

**Step 7: Edit the code to complete the submodel.**

1. Define the outputs in the *Calculation Function Executable Statements* section as follows:

```
C >>>>>>>>>>>>Calculation Function Executable Statements.
      vdot = 9.81d0 - fext/mass
      ydot = v
C <<<<<<<<<<<<End of Calculation Executable Statements.
      end
```

2. Optionally put checking code in the *Initialization Function Check Statements* of the initialization code. There is a big temptation in these tutorial examples to omit this but for serious submodels it is highly desirable to do it.

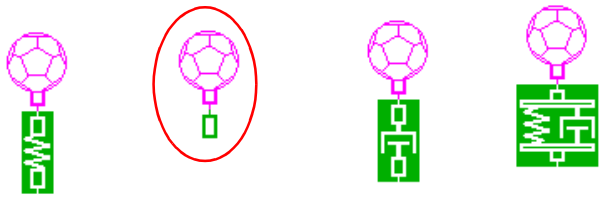
```
C >>>>>>>>>>>>Initialization Function Check Statements.
      if(mass .le. 0.0d0)then
         print*,'Mass should be greater than 0. Value is ',mass
         error = 2
      endif
C <<<<<<<<<<<<End of Initialization Check Statements.
      if(error .eq. 1)then
```

**Step 8: Compile the code (and correct any errors found).**

**Step 9: Check that you can use it in AMESim.**

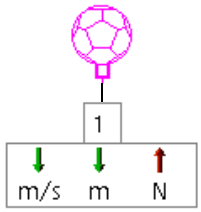
1. First verify that it will connect to icons in the (green) Mechanical library. It should connect to any linear shaft port of a green icon that supplies a force. Try these.

**Figure 4.40: Check that the ball connects.**



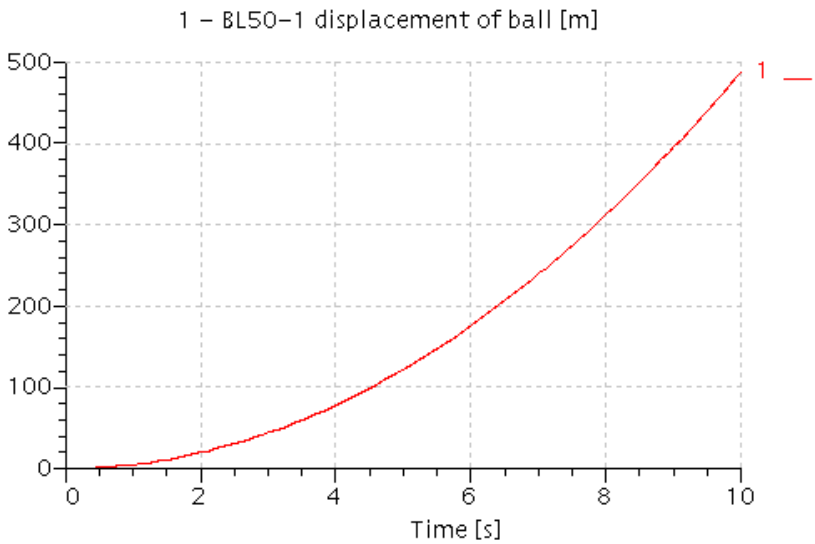
2. Connect a single ball icon to a zero force source (ringed in Figure 4.40). In *Submodel* mode show the external variables of the *BL50* are what they should be.

**Figure 4.41: External variables of BL50.**




3. With the default parameters, run a simulation. Plot various variables in the ball submodel. Note how the ball falls freely under gravity.

**Figure 4.42: The ball falls under gravity.**




## 4.2.3 Creating the floor submodel FL50

The submodel we will use for the floor will be called *FL50*. It will effectively provide a force corresponding to a spring damper system. This force will only apply if the displacement received from the ball exceeds a certain value.

**Step 1: Create a new submodel associated with the floor icon.**

**Step 2: Specify 3 external variables on the single port and set them as follows:**

| Field | Variable 1 | Variable 2 | Variable 3 |
|---|---|---|---|
| Type | basic variable (output) | basic variable (input) | basic variable (input) |
| Title | force provided by floor | velocity of impacting object | displacement of impacting object |
| Unit | N | m/s | m |
| name | fext | v | y |

Remember the order is important!

**Step 3: Set the number of real parameters to 3 and define them as follows:**

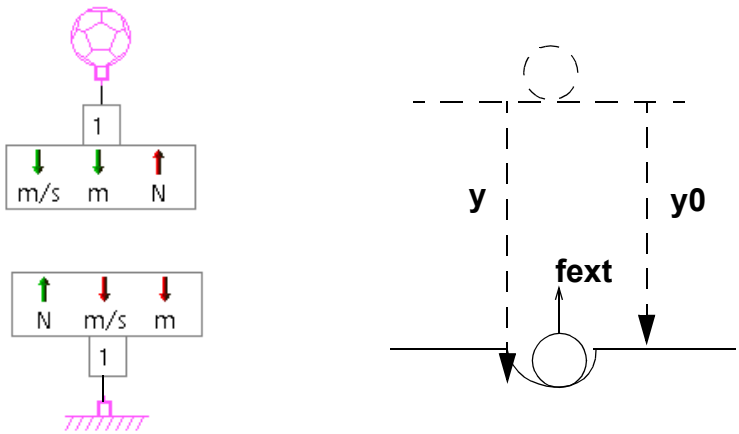
| Field | Parameter 1 | Parameter 2 | Parameter 3 |
|---|---|---|---|
| Title | displacement at which impacting object hits floor | spring rate between impacting object and floor | damping coefficient between impacting object and floor |
| Unit | m | N/m | N/(m/s) |
| Variable name | y0 | k | damp |
| Min. | 1 | 0 | 0 |
| Default | 10 | 1.0e5 | 1 |
| Max. | 100 | 1.0e8 | 100 |

Like all submodels, the purpose in life of *FL50* is to compute its outputs from its inputs. There is only one output. It is **fext** and the simplest way of defining **fext** is, writing in Fortran 77:

```
      if(y .ge. y0)then
C
C       The object is in contact with the floor.
C
         fext = k*(y - y0) + damp*v
      else
C
C       The object is free of the floor.
C
         fext = 0.0d0
      endif
```

Remember the sign convention, which is shown in Figure 4.43. If **y**, **y-y0** and **v** are positive which will be the case when the ball is in contact with the floor, both the spring force and viscous force will act upwards i.e. will make a positive contribution to **fext**.

**Figure 4.43: The ball falls to the floor.**




These lines of code are simple and express exactly what we want to do. However, unfortunately they completely ignore the discontinuity. To handle the discontinuity it is necessary to ensure the integrator always works on continuous equations. We could modify the second branch of this code as follows:

```
      else if(y .lt. y0)then
C
C       The object is free of the floor.
C
         fext = 0.0d0
      endif
```

Clearly this does exactly the same thing. Finally we modify the code as follows:

```
      if( disimp(y .ge. y0, ic(1)) )then
C
C       The object is in contact with the floor.
C
         fext = k*(y - y0) + damp*v
      else if( disimp(y .lt. y0, ic(2)) )then
C
C       The object is free of the floor.
C
         fext = 0.0d0
      endif
```

and this achieves our objectives. There are two key features in this code, which must now be explained. First there are two integer store array elements **ic(1)** and **ic(2)**. Remember that these elements have their values preserved between calls. The function *disimp* will set these to either 1 or 0 which are taken to be true and false respectively. The definition of the array elements is as follows:

- **ic(1)** set to true if the object is in contact with the ground i.e. $y \geq y0$,
- **ic(2)** set to true if the object is NOT in contact with the ground i.e. $y < y0$.

Thus one will be set to 1 and the other to 0.

Next we must define the function *disimp*. Users of C have the advantage that there is a header file called *ameutils.h* which is included in the code. This defines the function *disimp_* and a several hundred others. For Fortran users, if you declare a submodel as having discontinuities, this function will always be declared as follows:

```
      logical disimp
      external disimp
```

The first argument of *disimp* is of type *logical* and the second *integer* (and almost always it is an integer store variable). The function does a great deal of work managing discontinuities for you. The detail of this work is hidden and all you need worry about are the following:

- Make sure that **AMESet** knows that the submodel has discontinuities so that *disimp* is declared properly.
- Make sure that the logical conditions which form the first argument to the function are exhaustive (cover every possible case) and exclusive (have no overlap).

In C, since the first argument is a pointer to type int, it is necessary to declare two variables for the conditions

```
      int cond1, cond2;
```

and set them

```
cond1 = (*y) >= y0;
cond2 = (*y) < y0;
```

or even

```
cond1 = (*y) >= y0;
cond2 = !cond1;
```

The function *disimp_* is then used as follows:

```
if( disimp_(&cond1, &ic[0]) )
{
   /* Object is in contact with floor. */
   *fext = k*((*y) - y0) + damp*(*v);
}
else if( disimp_(&cond2, &ic[1]) )
{
   /* Object is free of floor. */
   *fext = 0;
}
```

Knowledge of the full details of what happens within *disimp* is unnecessary. However, you may find the following outline of the main stages useful:

At the start of the integration there is a special call and one of **ic(1)**, **ic(2)** will be set. This means one of the two possibilities is enabled.

After this the possibility selected will be used in calls to the submodel.

It may be that at some stage the logical condition of the selected branch becomes false. If this happens, the integrator will interpolate backwards looking for the time at which the discontinuity occurs. Eventually the discontinuity will be located as accurately as possible. Two times will be found which are very very close together one of which makes the condition true and the other false. In the code of the integrator these are referred to as **tl** and **tr** with **tl<tr**. The integrator then shuts down and restarts as if it where a completely new run with initial time **tr**. The values of the state and implicit values at the time **tr** are used as starting values.

- The first call to the submodels after the restart will be an initialization call just like at the start of the integration. This will interchange the two **ic** values, selecting the other branch.
- Note that the first call at the start of the run and the call immediately after a restart has **flag** = 0. In the previous example and in some other example in this chapter this fact is important. However, in this example it is not necessary to use the discontinuity variable **flag**.

Discontinuities involve changing from one regime, mode or state to another. Each regime has its own set of continuous equations. It is of the greatest importance that the conditions must be defined with great care. In the present example the

conditions are

```
y .ge. y0
y .lt. y0
```

Note we could have used conditions

```
y .gt. y0
y .le. y0
```

and these would have worked equally well. However, if we had used

```
y .ge. y0
y .le. y0
```

there would have been a lot of trouble. This is because these conditions are not exclusive – they overlap. If we tried the conditions

```
y .gt. y0
y .lt. y0
```

there would also be trouble because the condition is not exhaustive. The condition where *y=y0* is not covered.

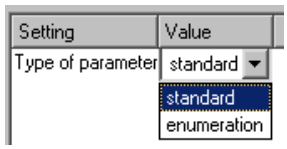
**The important thing to remember is the conditions must not overlap and they must cover all possibilities.** Below is an example where there are three possibilities:

```
if( disimp(x .le. xmin, ic(1)) )then

else if( disimp(x .ge. xmax, ic(2)) )then

else if( disimp(x .gt. xmin .and. x.lt.xmax, ic(3)) )then

endif
```

the code for each of the three branches being omitted. Provided *xmin* < *xmax*, the three conditions are **exclusive** and **exhaustive**. Naturally the initialization function should check that *xmin* < *xmax*.

You will now construct a submodel for our floor icon. The submodel will use the code for handling the discontinuities in the manner described above and also code which ignores discontinuities. This will enable you to see the two techniques compared in terms of run times, accuracy etc. To enable us to switch from one mode to the other, an integer parameter will be used. These are similar to real parameters but, since they are integers, do not have units. They are chiefly used to allow you to select from several options.

### Step 4: Set the integer parameter in the same way as the real parameters. A suggested name for this parameter is mode and for the title, minimum, default and maximum values:

| Field | Parameter |
|---|---|
| Type of parameter | standard   |
| Name | mode |
| Title | *1 for discontinuity handling 2 for ignore discontinuities* |
| Minimum | 1 |
| Default | 1 |
| Maximum | 2 |

**Step 5: Generate the code in your preferred language and make insertions in executable section of the calculation routine. In Fortran these will be:**

**In F77:**

```
            if(mode .eq. 1)then
      C
      C        Full discontinuity handling selected.
      C

               if( disimp(y.ge.y0, ic(1)) )then
      C
      C            The object is in contact with the floor.
      C
                  fext = k*(y - y0) + damp*v
               else if( disimp(y.lt.y0, ic(2)) )then
      C
      C            The object is free of the floor.
      C
                  fext = 0.0d0
               endif
            else
      C
      C            Living dangerously! No discontinuity handling.
      C
```

```
            if(y .ge. y0)then
C
C            The object is in contact with the floor.
C
            fext = k*(y - y0) + damp*v
            else
C
C            The object is free of the floor.
C
            fext = 0.0d0
            endif
         endif
```

**In C:**

```
if(mode == 1)
{
   /* Full discontinuity handling selected. */
   cond1 = *y >= y0;
   cond2 = !cond1;
   if( disimp_(&cond1, &ic[0] ) )
   {
      /* The object in contact with the floor. */
      *fext = k*(*y - y0) + damp*(*v);
   }
   else if( disimp_(&cond2, &ic[1] ) )
   {
      /* The object is free of the floor. */
      *fext = 0.0;
   }
}
else
{
   /* Living dangerously! No discontinuity handling. */
   if(*y >= y0)
   {
      /* The object in contact with the floor. */
      *fext = k*(*y - y0) + damp*(*v);
   }
   else
   {
      /* The object is free of the floor. */
      *fext = 0.0;
   }
}
```

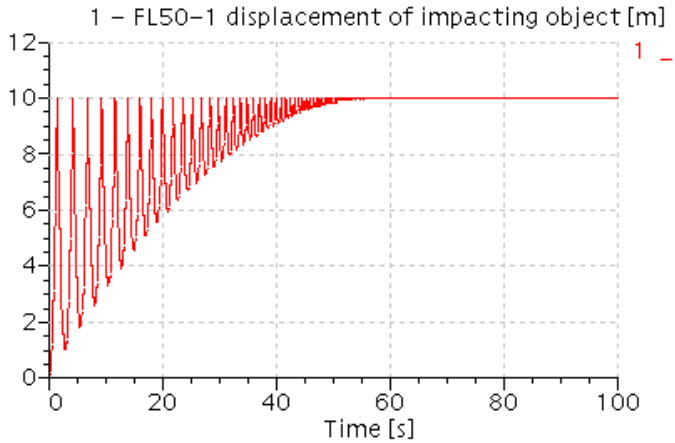
### Step 6: Compile the code. If necessary, make corrections to any errors detected by the compiler.

### Step 7: Start AMESim and connect the ball icon to the floor icon.

The submodels should be selected automatically. Run several simulations with run statistics enabled with and without discontinuity handling in *FL50*. You will

probably find that, for most but by no means all sets of parameters, the runs are slightly faster with discontinuity handling. If you enable extra printout at discontinuity points, you will find the points at which the ball contacts and leaves the floor is located very precisely with discontinuity handling, even with a coarse communication interval. To determine these points without discontinuity handling, you must set a very small communication interval.

**Figure 4.44: The displacement of the ball.**




Increase the damping coefficient in the floor icon *to 10 N/(m/s)* and run the simulation for at least 20 seconds. You will find that there are a finite number of bounces and that eventually the ball comes to rest. It is much easier to identify the individual bounces when there is discontinuity handling. You can save results from one simulation and load them back after performing another simulation. You will find that by zooming in you can see a difference between the results with and without discontinuity handling. If you prefer, plot the displacement subtracted from 10 m to get the height of the ball above the floor.

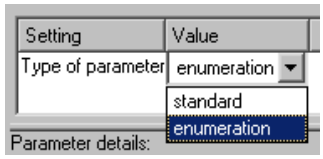
## Use of an enumeration integer parameter

*FL50* in its present state uses a **standard** integer parameter. It is also possible to use an **enumeration** integer parameter. It is easy to convert from standard to enumeration.

**Step 1: If necessary, reload FL50 into AMESet.**

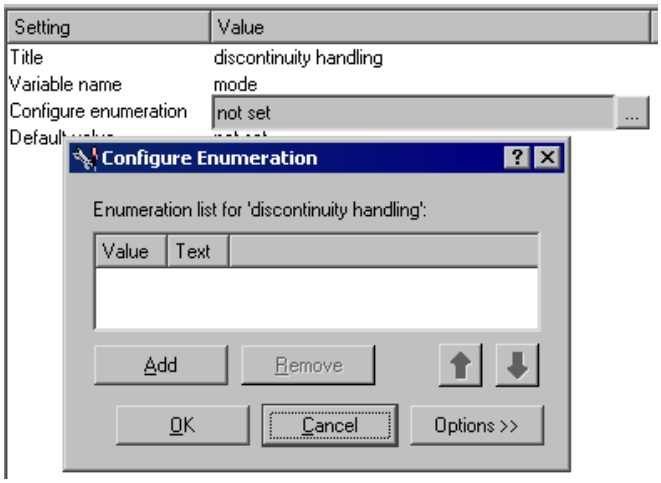
**Step 2: Select the integer parameter and modify it to make a suitable enumeration integer parameter. Do this in the following stages:**

1. Change the *Type of Parameter* field to *enumeration*.

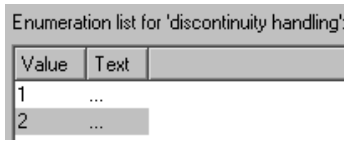



2. Change the *Title* field to *discontinuity handling*.
3. The *Configure enumeration* field is currently displays *not set*. Click on the button to create the *Configure Enumeration* dialog box shown in Figure 4.45.

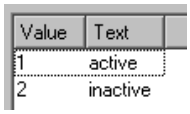
**Figure 4.45: The Configure Enumeration dialog box.**




4. It is necessary to add two character strings that will take the place of the values 1 and 2. Click on the *Add* button twice.




5. Enter the text strings *active* and *inactive* in the *Text* column.



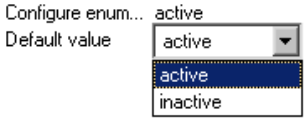

6. Clicking on the *Option* button produces an expanded dialog box which offers the possibility of hiding parameters according to value is set for the enumeration integer parameter. However, in this case this is not useful so click on the *OK* button. Notice how the *Parameter details* have changed.

**Figure 4.46: Parameter details for an enumeration integer parameter.**

Parameter details:

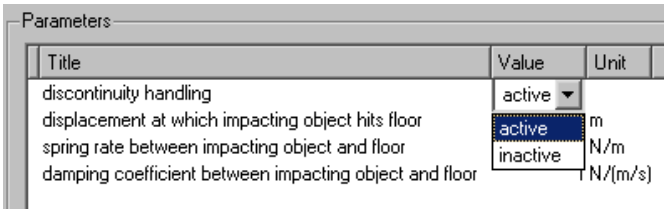
| Setting | Value |
|---|---|
| Title | discontinuity handling |
| Variable name | mode |
| Configure enumeration | active |
| Default value | active |

The *Default value* has been set to the first string in the list which is *active*. This can be changed to any of the string values the parameter can take.
However, leave the string as *active*.




Do a *Parameter Mode Preview* and note how you can change the text string for the enumeration parameter.

**Figure 4.47: Parameter mode preview for the enumeration integer parameter.**



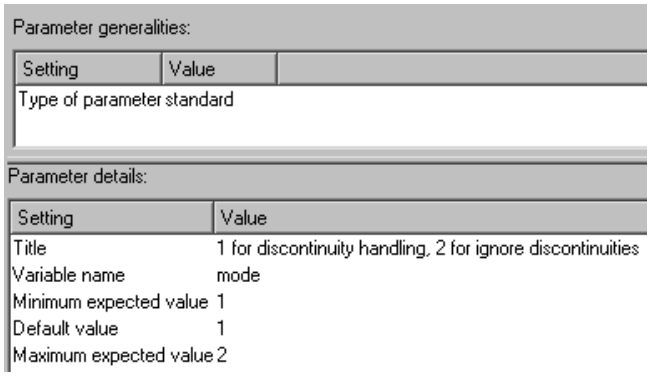

7. Save your submodel.
8. What changes need to be done to the code? Actually none. Look at the code in your editor. You will find it looks very similar to how it did when it was a standard integer parameter. Within the generated code is a integer parameter taking the value 1 to 2 just like when it was a standard integer parameter. The text string *active* and *inactive* appear only in the *Change Parameters* dialog box.
9. Compile your submodel and reselect it in **AMESim**, verify than the *Change Parameter* dialog box is different but it gives the same result.

## Using AMELexicon to set parameters

*AMELexicon* is a tool dedicated to helping you achieve consistency in submodel titles, units etc. Many submodels contain an enumeration integer parameter like the one we want to create. We can use *AMELexicon* to find these and copy-paste into FL50.

We now review the stages for changing the standard parameter to an enumeration parameter using *AMELexicon*. We assume that starting point is the standard integer parameter.

**Figure 4.48: The standard integer parameter in FL50.**




1. Start *AMELexicon* using **Tools ▶ AMELexicon...**.The *AMELexicon* dialog box appears as shown in Figure 4.49.

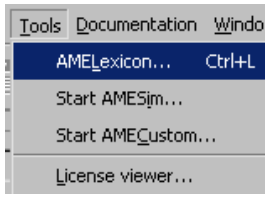
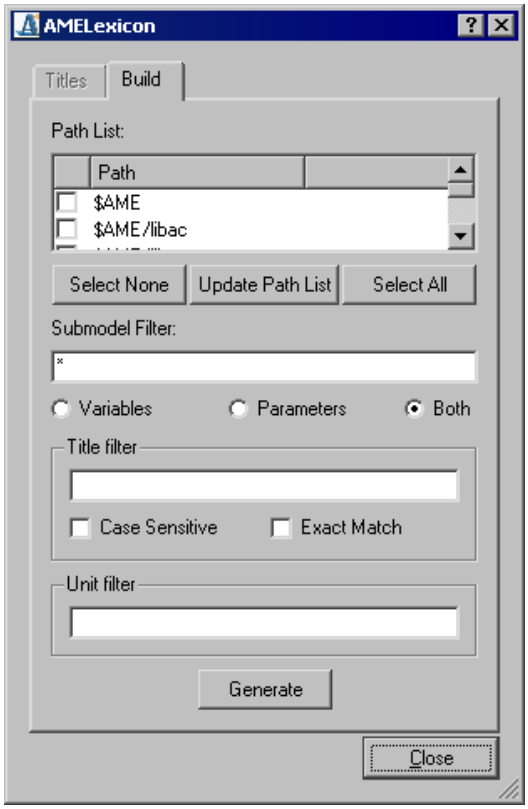
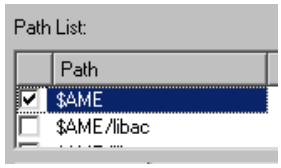



**Figure 4.49: The AMELexicon dialog box.**

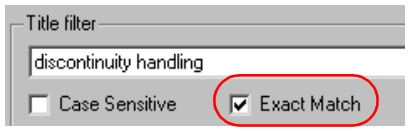


2. At the top is *Path List* which is constructed from your current path list. Initially no items are checked. Check the *$AME* item.



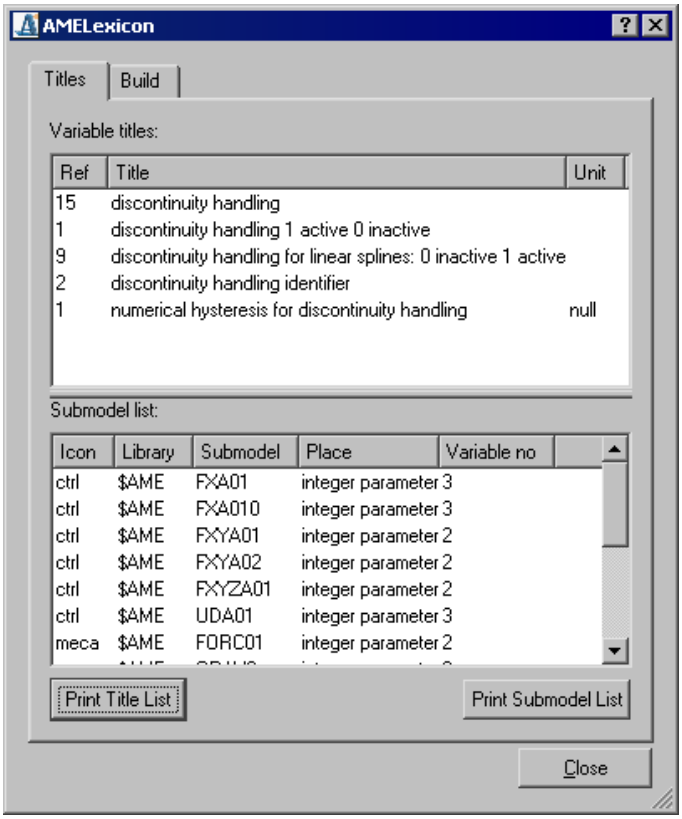

3. Under *Submodel Filter* is a '*'. This is a wild card indicating all submodels are to be searched. Leave it like this but select the *Parameters* radio button. We want to search all the parameters of all the submodel in $AME.

4. Under *Title Filter* enter the text *discontinuity handling*. Tick the check box *Exact Match*.

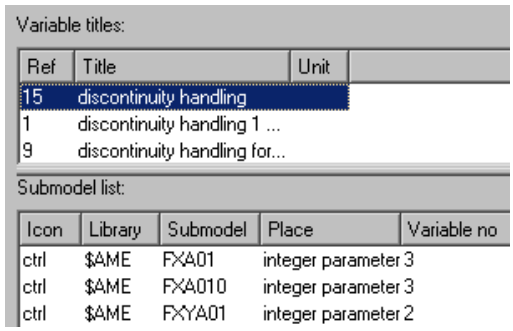



5. Click on *Generate* to create lists of parameter of submodels in $AME containing the exact text *discontinuity handling*.

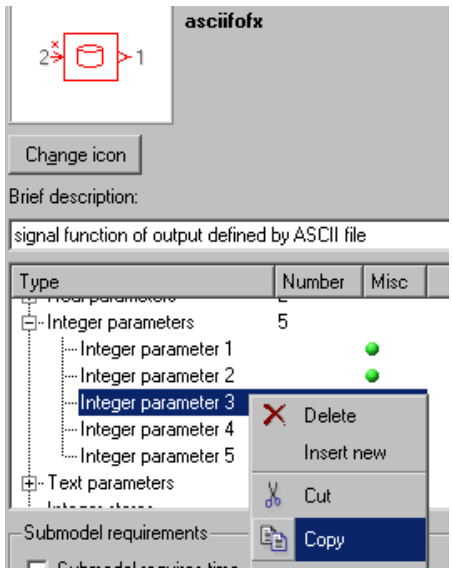
**Figure 4.50: AMELexicon with lists generated.**



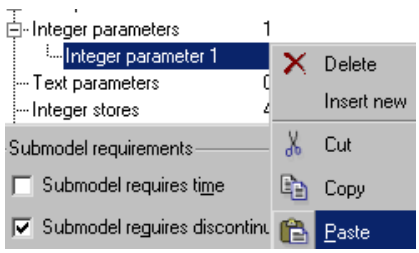
6. The parameter we want is the first one and it is used in 15 submodels. Click on this and The *Submodel list* reconstructs to show these 15 submodels.




7. Double click on *FXA01* and it is loaded into **AMESet**.
8. Locate integer parameter number 3.
9. Right click on this parameter and select *Copy*.
10. Close *FXA01* or use the *Windows* menu to make *FL50* the active submodel.




11. Right click on the integer parameter of *FL50* and select *Paste*. The new details appear



12. There is only one problem: in the code generated the variable name is *mode* where in *FXA01* it was *disc*. Change *disc* to *mode*.
13. Save and compile the submodel.

| Setting | Value |
|---|---|
| Type of parameter enumeration | |

Parameter details:

| Setting | Value |
|---|---|
| Title | discontinuity handling |
| Variable name | disc |
| Configure enumeration | inactive |
| Default value | active |

In this example it was probably much quicker to do the changes without *AMELexicon*. However, if you construct a lot of submodels it becomes very important that titles and units are consistent. *AMELexicon* is very good for this.

## 4.2.4 Activity index computations

It is possible to create large numbers of very useful submodels that do not contain activity variables. However, there are strong reasons for adding these features if your submodels are to be used in serious big systems. This is illustrated in Chapter 8 of the **AMESim** manual. The current two submodels are certainly not likely to be used in serious big systems! However to illustrate the process, we are going to introduce activity index computations in both the ball and the floor submodels.

This is done by adding an internal variable of type *activity variable*. For this variable we must define a physical type (*R*, *C*, *I*), a physical domain (*hydraulic*, *mechanical*, *electrical*, ...) and a suffix. You do not have to give it a special title because this is constructed from the other fields. The units are always *J*.

Note that none of the other submodels you have created so far need activity index.

- The rack submodel *RACK50* is an ideal transformer. There is no dissipation (*R*), there is no inertia (*I*) and no energy is stored (*C*).
- The prime mover *PM50* is a pure source.
- The square wave submodel *SQ50*, like all the submodels in the Signal, Control and Observers does not involve energy exchange.

For each activity variable, **AMESet** automatically defines a power variable which is declared at the beginning of the calculation function. This power variable must be assigned in a special section of the calculation function/subroutine known as the *Activity Computation Statements*. The power is then used by **AMESet** in order to calculate the corresponding activity.

In the case of a linear mechanical submodel, the power is defined as follows:

$$P = F \times V$$

where $F$ is a force applied to the submodel and $V$ its linear velocity.

## Activity index in the ball submodel

Concerning the ball submodel, we need one *activity* variable that will be associated with the inertial power of the ball.

**Step 1: Open the ball submodel BL50.**

**Step 2: Set the number of internal variable to 1, set its type to activity variable and define it as follows:**

| Field | Value |
|---|---|
| Physical type | I |
| Physical domain | Mechanical |
| Variable name suffix | mass |

This activity variable will be related to the inertial power of the ball. As you introduce an activity variable, you will find that the number of integer stores is incremented by 1.

**Step 3: Generate and examine the code.**

1. Examine the calculation function/subroutine.

   You will find that the power variable is a local variable declared as follows:

```
      double precision powImass
```

   and the activity variable is *actImass* which is passed through the argument list. There is also a special section added near the end of the code:

```
      if (isactivity().eq.1) then

C     Set the following power variables:

C        powImass = ??

C     >>>>>>>>>>>>Activity Computation Statements.
C     <<<<<<<<<<<<End of Activity Computation Statements.

      call setactivity(ic(1), actImass, powImass, «BL50», n,
     +      «mechanical», «I»)
      endif
```

   Note the call to the function **isactivity**. This is used to determine if the calculations are to be performed. The call to **setactivity** processes the *powImass* variable and produces the activity *actImass*. Note that it uses an integer store.

1. Check that the integer store is declared properly with dimension 1.

### Step 4: Edit the submodel code.

In the *Activity Computation Statements* section, define the power associated with the mass of the ball. The power is obtained by multiplying the force (*mass*vdot*) by the velocity (*ydot*).

```
C     >>>>>>>>>>>>Activity Computation Statements.
      powImass = mass*vdot*ydot
C     <<<<<<<<<<<<End of Activity Computation Statements.
```

### Step 5: Compile and save BL50.

## Activity index in the floor submodel

Concerning the floor submodel, we will use two *activity* variables that will be associated with the capacitive (spring) and dissipative (damper) power of the submodel.

### Step 1: Open the floor submodel FL50.

### Step 2: Set the number of internal variables to 2, set their type to activity variable and define them as follows:

| Field | Variable 1 | Variable 2 |
|---|---|---|
| Physical type | C | R |
| Physical domain | Mechanical | Mechanical |
| Variable name suffix | spring | damper |

### Step 3: Edit the submodel code.

1. In the *Activity Computation Statements* section, define the power associated with the capacitive and dissipative elements of the floor submodel.

   In a linear mechanical submodel, the power is obtained by multiplying the force by the velocity. For the dissipative (R) element, the force is *damp*v* and the velocity is *v*. For the capacitive (C) element the force is *k*(y-y0)* and the velocity is *v*. Thus we get:

```
C     >>>>>>>>>>>>Activity Computation Statements.
      powCspring = k*(y-y0)*v
      powRdamper = damp*v*v
C     <<<<<<<<<<<<End of Activity Computation Statements.
```

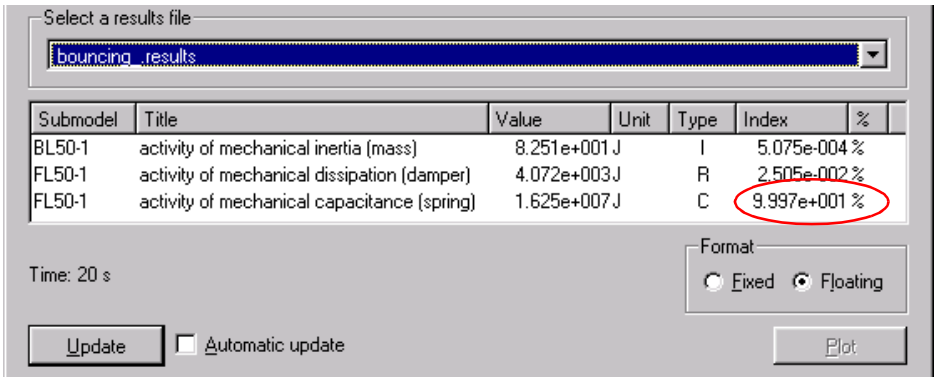
2. Check that the number of integer stores is correctly dimensioned at 4.

### Step 4: Compile and save FL50.

## Activity index computation in AMESim

Open the **AMESim** model using *BL50* and *FL50* and do **Tools ▶ Check submodels** in order to use the latest versions of these submodels. The activity index calculations can be enabled from the *Run parameters* dialog box. If you run a new simulation and then select the menu **Tools ▶ Activity index**, an *Activity Index List* dialog box appears showing the results below. As you can see, the capacitive activity of the floor is 99.97% of the total activity of the model.

**Figure 4.51: Look at the activity of the floor capacitance**



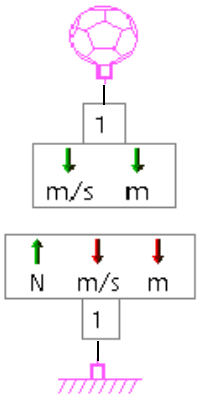

## 4.2.5 BL51: a submodel employing a coefficient of restitution

Next you will construct two completely different submodels for the ball and floor based on different modeling assumptions. These will be called *BL51* and *FL51* respectively. The assumptions are:

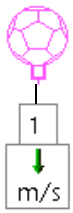
> **when the ball hits the ground, its velocity is reversed in sign and its magnitude is multiplied by a constant factor less than one.**

This factor is sometimes called the **coefficient of restitution**.

*BL50* dealt with the displacement and velocity and we will do the same with *BL51*. Note that there is now no concept of an external force and we can remove this force from the port of *BL51*. This means that external variables of *BL51* look as shown on the right and that it would still connect to the floor submodel *FL50*. This is very bad because the purpose in life of *FL50* is totally unrelated to that of *BL51*.



To get over this we will remove the displacement external variable from *BL51* and make it an internal variable. *BL51* will then have external variables as shown on the right and will now be incompatible with *FL50*. We will later build a special *FL51* which is compatible with BL51.




**Step 1: Ensure *BL50* is loaded. To save time, you are going to base the new submodel on the old.**

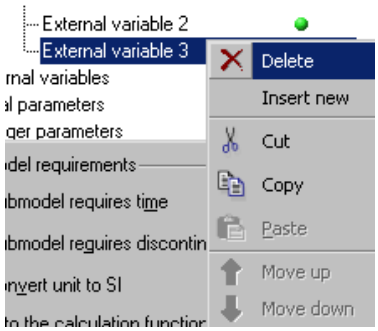
**Step 2: Use File▶Save as and save the submodel as BL51.**

Remember there is now no external force. Hence we also have 2 variables on the single port which are the velocity and displacement.

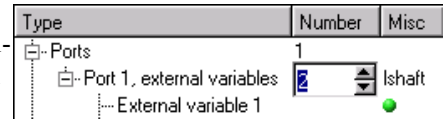
**Step 3: We have to delete the last external variable.**

There are two simple ways of doing this:

**Figure 4.52: Deleting an external variable.**




1. Right click on *External variable 3* and select *Delete*. You can also select *Cut*. (The difference is that with *Cut* you can always *Paste* it after.) Alternatively:
2. Edit the number of variables on port 1 to 2. Check that the two variables left are what they should be.




**Step 4: We want to move the displacement external variable to an internal variable. This is done very easily.**

1. Highlight external variable 2. Check that you really have got the right one: it is the displacement. With the right button menu select *Copy*.
2. Select *Internal variable 1*.
3. With the right button menu select *Paste*: the previous *activity* variable is overwritten by the displacement variable.
4. Remove the second external variable as explained in **Step 3**.

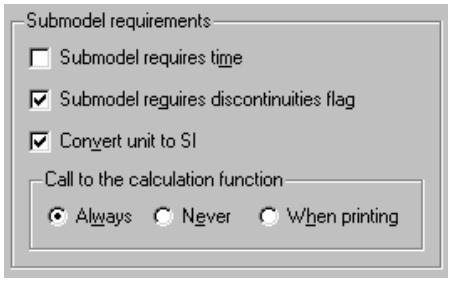
Now we will consider the code for *BL51*. With the coefficient of restitution represented by *coefr*, the most obvious way of coding this is as follows:

```
            if(y .gt. y0)then
      C
      C            Ball has hit the floor.
      C
               y = y0
               v = -coefr*v
            endif
            ydot = v
            vdot = 9.81
```

This is the most extreme form of discontinuity in which there are jump changes in the state variables. It is almost guaranteed to cause severe problems and very likely complete failure in the integration algorithm. It is common practice in simulation code to protect against this sort of abuse by not allowing a model to change state variables. **AMESim** always gives access to a copy of the state variables and so any changes you might make to state variables do not normally reach the integrator. The only exception to this is as follows:

**When flag = 0, you are allowed to change the value of explicit states, implicit states or constraint variables. At no other times are you allowed to change these values.**

### Step 5: Tick the check box *Submodel requires* ***discontinuities flag.***




Provided the submodel is declared as having discontinuities, we have access to the **flag** variable and we can rewrite the calculation section as follows:

```
            if(flag .eq. 0)then
      C
      C            Integration has just started or restarted.
      C            Check value of y.
      C
               if(y .gt. y0)then
      C
      C                Ball has hit the floor.
      C
                       y = y0
                       v = -coefr*v
```

```
            endif
         endif

         if( disimp(y.le.y0, ic(1)) )then
C
C              Ball is still falling freely
C
            ydot = v
            vdot = 9.81
         else if( disimp(y.gt.y0, ic(2)) )then
C
C              Ball is in illegal position
C
            ydot = ??
            vdot = ??
         endif
```

There are two problems here. First it is not clear how we should set **ydot** and **vdot** when **y>y0**. However, after a little thought it is clear that the second branch is totally unnecessary. A little explanation is necessary:

- At the start of the integration and after any restart *flag* will be 0 and hence $y$ will be changed so that $y \le y0$. It follows that the first branch is always selected.
- When the condition $y \le y0$ is false, the first branch will still be executed. This is essential to ensure that the equations are continuous. As soon as the condition is false the function disimp will scream and the integrator will locate the discontinuity and organize a restart.
- During the first call after the restart, flag = 0 and $y$ will be reset and so the condition $y \le y0$ is true again.

It follows that we can delete the second branch completely.

If you are very observant, you will notice that if the starting value of **y** was set such that **y>y0** and in addition **v<0**, there would be a major problem. The value of **v** would be reset to a positive value and the ball would be traveling downwards. This would trigger a discontinuity immediately after the first integration step. We make the following modification in an attempt to cope with this:

```
         if(flag .eq. 0)then
C
C              Integration has just started or restarted.
C              Check value of y.
C
            if(y gt. y0)then
C
C                 Ball has hit the floor.
C
               y = y0
```

```
                if(v .gt. 0.0d0)then
                   v = -coefr*v
                endif
             endif
          endif
          if( disimp(y.le.y0, ic(1)) )then

C
C            Ball is still falling freely
C
             ydot = v
             vdot = 9.81
          endif
```

Again, if you are very observant, you will notice that if initial value of **y** is set to **y0** and **v = 0** there will be major problems. However, it is time to get started and we will return to these problems when we have the model running and can study the pathological cases in detail.

Notice that the only force applied to the ball in this equation is the weight of the ball. There is no reference to any external force. Hence it is not necessary for the floor submodel to return any value for the force between the ball and the floor. It is probably more convenient to define the values of the displacement at which the ball hits the floor and the coefficient of restitution within BL51 as real parameters.

**Step 6: Alter the number of real parameters to 2. Set the new real parameters as follows:**

| Field | Parameter 1 | Parameter 2 |
|---|---|---|
| Title | displacement at which ball hits floor | coefficient of restitution |
| Unit | m | null |
| Variable name | y0 | coefr |
| Min. | 1 | 0 |
| Default | 10 | 0.8 |
| Max. | 100 | 1.0 |

**Step 7: Modify the new brief description to *AMESet tutorial bouncing ball 2*. Generate the code for the submodel.**

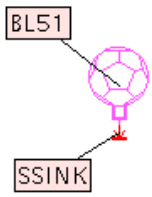
**Step 8: Load the code into your favorite editor and insert the Fortran code of the previous page into the calculation function/subroutine.**

Alternatively, if you are using C, you are probably using an integer local variable *cond*. Here is some code in C for this example. The extra definition of *cond* is essential.

```
cond = *y <= y0;
if(*flag == 0)
{
   /* Integration just started or restarted.
      Check position of ball. */
   if(*y > y0)
   {
      /* Displacement is invalid and must be reset.
         Bounce the ball!  */
      *y = y0;
      /* If necessary, reset velocity. */
      if(*v >= 0.0)
      {
         *v = -coefr*(*v);
      }
       /* The state has changed and must be reset. */
      cond = 1;
   }
}
 if(disimp_(&cond, &ic[0]))
{
   *ydot = *v;
   *vdot = 9.81;
}
```

**Step 9: Compile your submodel. Be careful of any left over code from BL50. For instance, any references to the old variable *mass* must be removed.**

**Step 10: Use your new submodel in AMESim. It cannot be connected to the old floor submodels. Connect it instead to the general signal stopper. With the default parameters run a simulation and plot a graph of *displacement of ball*.**




You will find all is well for a 10s run but if you increase the final time to 20s and enable discontinuity the situation is very different! If you do this be ready with the stop button!

**Figure 4.53: The ball does not stop bouncing**

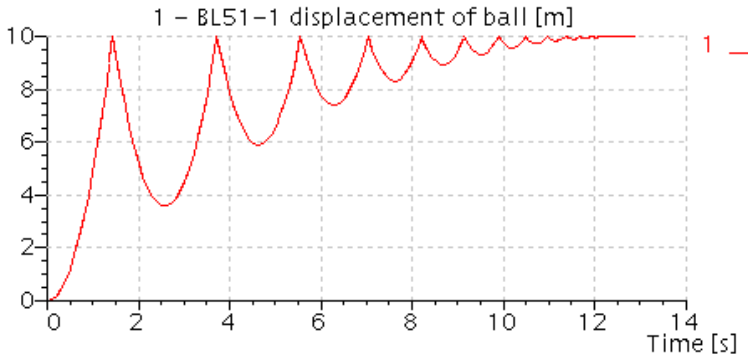
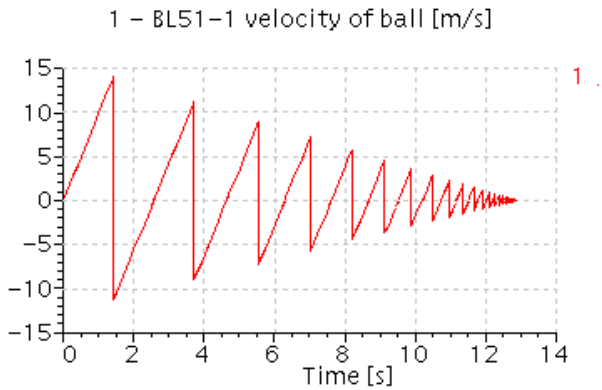



**Figure 4.54: The discontinuities get ever closer.**

```
BL51 instance 1 discontinuity at Time = 12.8506
BL51 instance 1 discontinuity at Time = 12.8506
BL51 instance 1 discontinuity at Time = 12.8506
BL51 instance 1 discontinuity at Time = 12.8506
BL51 instance 1 discontinuity at Time = 12.8506
BL51 instance 1 discontinuity at Time = 12.8506
BL51 instance 1 discontinuity at Time = 12.8506
```

Note how the discontinuity handling picks out very sharply the instantaneous changes in the velocity.

**Figure 4.55: Instantaneous changes in velocity.**




What is happening is that the modeling assumption imply equations which further imply an infinite number of bounces before the ball comes to rest. Numerically this is a disaster.

Which is the better submodel of the bouncing ball? Almost certainly *BL50* but *BL51* is certainly interesting! Have you any ideas on how to overcome the problem?

## 4.2.6 FL51: a floor submodel for BL51

The times at which the ball hits the ground will be very well picked out in plots if we run the simulation with *Discontinuities printout* enabled. It would be instructive to pick out the points where a maximum height is reached.

*FL51* will accept the one variable from *BL51* which is a velocity.We will integrate the velocity to compute the total distance traveled by the ball as follows:

$$\frac{\delta s}{\delta t} = |v|$$

Note that the function $|v|$ has a discontinuity in its first derivative. If we use the following code, we will pick out the points at which $v$ changes sign as discontinuity points:

```
            if( disimp(v.ge.0.0d0, ic(1)) )then
      C
      C         The sign of v is positive.
      C
               sdot = v
            else if( disimp(v.lt.0.0d0, ic(2)) )then
      C
      C         The sign of v is -ve.
      C
               sdot = -v
            endif
```

**Step 1: Load the old floor submodel FL50.**

**Step 2: Save it as FL51.**

**Step 3: Remove the output external variable and the displacement input leaving just the velocity input. Remove all existing real parameters and internal variables.**

**Step 4: Create a new internal variable as follows:**

| Field | Internal Variable 1 |
|---|---|
| Type | explicit state variable |
| Title | total distance traveled by impacting object |
| Unit | m |
| name | s |
| derivative name | sdot |
| Min. | 0.0 |
| Default | 0.0 |
| Max. | 0.0 |

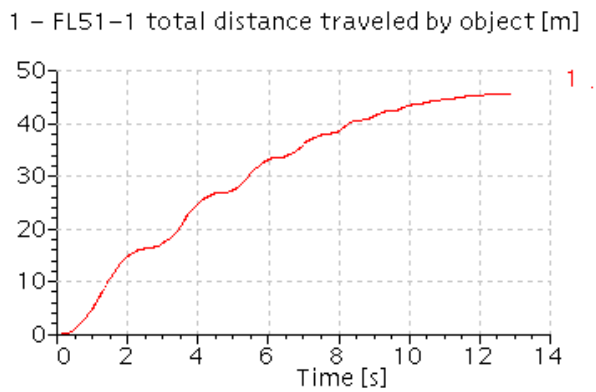
Note that minimum, default and maximum values have been set to the same value. This is a very useful 'trick' because it means that the initial value cannot be set when the submodel is used under **AMESim**. Only the submodel writer can reset this value directly. This is because there is access to all state variables in the initialization routine of submodels. If the value is not reset in the initialization routine, it will have the default value: 0.0 in this case. This technique can also be used for implicit and fixed variables.

**Step 5: Insert the code to perform the calculation of *sdot*. Compile and debug as necessary.**

**Step 6: Use the submodel in AMESim together with *BL51*. Plot a graph of the total distance traveled.**

Note how the distance approaches a value asymptotically.

**Figure 4.56: Asymptotic curve of the distance traveled**




Note also how BL50 and FL50 are a compatible pair as are BL51 and FL51 but you cannot pick and mix.

## 4.2.7 A final word on BL51

There are various ways of curing the problem. One example is given below. It required several attempts before it worked properly!

```
      if(flag .eq. 0)then
C
C           Integration has just started or restarted.
C           Check value of y.
C
         if(y .gt. y0)then
C
C           Ball has hit the floor.
C
            y = y0
            if(v .gt. 0.0d0)then
               v = -k*v
C
C               If bounce velocity is very small,
C               reset it to zero.
C

               if(v .le. vtol)then
C
C                       Ball has stopped bouncing.
C
                  v = 0.0d0



                  ic(2) = 1
               endif
            endif
         endif
      endif
      if(ic(2) .eq. 0)then
C
C       Ball is bouncing.
C
if( disimp(y.le.y0, ic(1)) )then
C
C           Ball is still falling freely
C
            ydot = v
            vdot = 9.81d0
         endif
      else
C
C       Ball has stopped bouncing.
C
         ydot = 0.0d0
         vdot = 0.0d0
      endif
```

This involves an extra real parameter with name *vtol* introduced into BL51. This is set to a small value (e.g. 1.0e-6) and is used to stop the bounce and also a second integer store ic(2).

Note that in this code **ic(2)** is not initialized to 0. This initialization can be done in

executable code section of the initialization routine.

The bouncing ball is a rich source of interesting modeling problems. An obvious extension of the model is to make the motion two-dimensional introducing a horizontal displacement **x** and velocity **u**. You can then have two walls introducing a bounce in the horizontal direction. If you have time, you can develop this model and simulate a game of squash!

## 4.2.8 Use of disloc

So far you have used the discontinuity handling functions *distim* and *disimp*. For more than 95% of submodels with discontinuities these will provide all the functionality necessary. However, there is a third discontinuity function *disloc*. This does much the same as *disimp* but many features, which are automatic in disimp, are left to the user in *disloc*. The function *disimp* was written as a much easier to use replacement for *disloc*. However, many experienced **AMESim** submodel developers continued to use *disloc* because they felt they had more control and could employ a number of 'tricks' which were impossible with *disimp*.

The rest of this section comprises a description of *disloc*. It is suggested that, if you are reading this chapter for the first time, you skip the rest of this section.

The classic use of *disloc* has the following form:

```
      if(flag .eq. 0)then
C
C       Integration has just started or restarted.
C       Set value of ic(1).
C
         if(condition)then
            ic(1) = 1
         else
            ic(1) = 0
         endif
      endif

      if(ic(1) .eq. 1)then
C
C       some statements here.
C
         logi = .not.(condition)
         call disloc(logi)
      else
C
```

```
C       some other statements here.
C
         logi = condition
         call disloc(logi)
      endif
```

where **logi** is automatically declared *logical* for F77 and type *int* for C and condition is replaced by something like:

```
      x.le.x0
```

in which case .not.(condition) will be replaced by

```
      .not.(x.le.x0)
```

or equivalently

```
      x.gt.x0
```

It is useful to construct a table from these values as follows:

| ic(1) | Condition for being in region | Condition for leaving region |
|---|---|---|
| 1 | x.le.x0 | x.gt.x0 |
| 0 | x.gt.x0 | x.le.x0 |

Note that the same rules about an exhaustive and exclusive set of conditions that applied to *disimp* also apply to *disloc*.

```
      if(flag .eq. 0)then
C
C       Integration has just started or restarted.
C       Check sign of v.
C
         if(v .ge. 0.0d0)then
            ic(1) = 1
         else
            ic(1) = -1
         endif
      endif
      if( ic(1).eq.1)then
C
C       The sign of v is positive.
C


         sdot = v
         logi = v.lt.0.0d0
         call disloc(logi)
      else
C
C       The sign of v is -ve.
C
         sdot = -v
         logi = v.ge.0.0d0
         call disloc(logi)
      endif
```

Note that the code is slightly more complex and there are more opportunities for getting it wrong. Only one integer store value is used instead of two but this is hardly worth the greater complexity. In most cases it really is better to use *disimp*.

Why then do some users prefer to use *disloc* on occasions? Here is an example of a section of code taken from the submodel of a check valve which employs hysteresis.

```
      dp = pin - pout
      if(flag .eq. 0)then
         if(dp .ge. 0.0d0)then
C
C               Check valve is open.
C
            ic(1) = 1
         else
C
C               Check valve is shut.
C
            ic(1) = 0
         endif
      endif
      if(ic(1) .eq. 1)then
C
C           Check valve is open.
C
         qout = dp*k
C
C           Check for check valve shutting
C
         logi = (dp .lt. -hys)
         call disloc(logi)
      else
C
C           Check valve is shut
C
```

```
         qout = 0.0d0
C
C           Check for check valve opening.
C
         log1 = (dp .gt. hys)
         call disloc(logi)
      endif
```

The hydraulic check valve submodel on rare occasions ‘chattered’. This means that it opened and closed rapidly which generated many discontinuities resulting in a slow simulation. This can occur when the system tries to achieve a steady state

with values, which give a pressure drop across the check valve corresponding to the opening value. i.e. **dp** = 0. If this happens, variations in pressure due to integrator 'noise' can open and close the valve. By reducing the integrator tolerance a cure can often be obtained but the code above adopts a different approach.

The quantity **hys** is a small pressure drop e.g. 0.00001 bar. The trick here is to break the normal rules. Constructing a table for the two states we have:

| ic(1) | condition for being in the region | condition for leaving region (logi) |
|---|---|---|
| 1 | `dp.ge.0.0d0` | `dp.lt.-hys` |
| 0 | `dp.lt.0.0d0` | `dp.gt.hys` |

The conditions in the second column are exclusive and exhaustive but those in the third column are not. In addition the conditions in the third column are not the opposite to those in the second column.

Techniques like this can be very useful but naturally great care in coding and testing are necessary.

## 4.3 A submodel using duplicate variables

**Objectives**

- To see how duplicate variables can be used to break algebraic loops.
- To gain some understanding of the **AMESim** sort process.

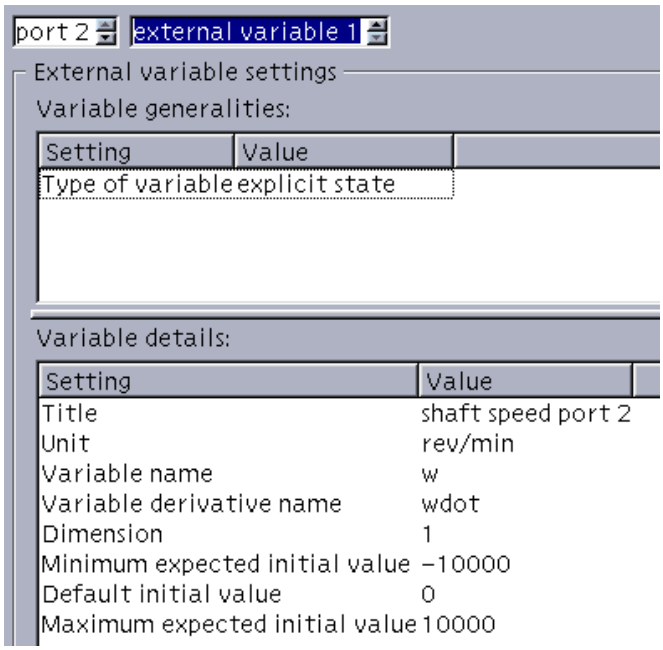
**Step 1: Click on the icon shown (in the *Mechanical* category) and select the existing submodel *RL02*.**

**Step 2: File ▶ Save as and specify *RL50*.**

**Step 3: Examine all the external variables.**

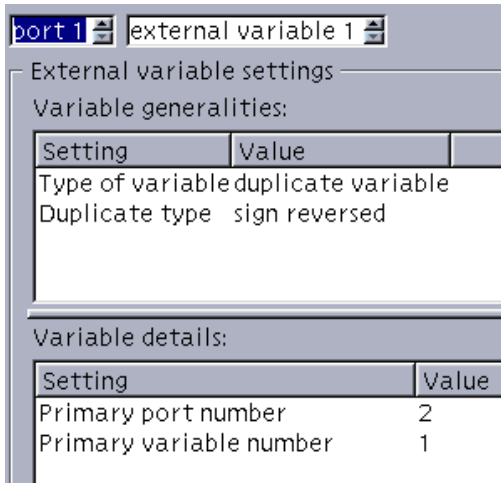
You will find that on port 2 the first external variable is a state variable.

**Figure 4.57: External variable is an explicit state.**

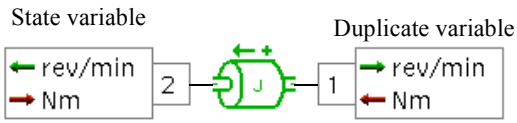



On port 1 the first external variable is a duplicate variable.

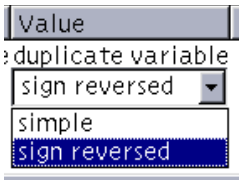
**Figure 4.58: External variable is a duplicate.**




Note that it must be specified what it is a duplicate of. It is a duplicate of the rotary speed state variable.



Duplicate variables come in two types: **simple** and **reversed sign**. The rotary speed is a quantity which has a direction associated with it. With the **AMESim** sign convention if the state variable on port 2 is 2000 rev/min, the variable on port 1 is -2000 rev/min. This duplicate variable is **reversed sign**.




**Note:** With duplicates of variables that have a direction associated with them, the type will be **reversed sign**. Other examples are mass flow rate, volumetric flow rate, displacement, acceleration, force, torque.

With duplicates of variables that have no direction associated with them, they will be of type **simple**. Examples are pressure, volume, mass etc.

**Step 4: Without changing anything, generate the code and view it in an editor. For this example you should use C or will lose the executable statements inherited from *RL02*.**

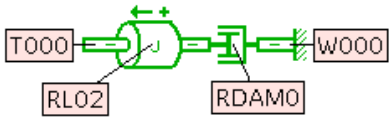
The code will be identical to *RL02* apart from the function names. N**otice that the duplicate variable *wdup* is not available.** This is because **AMESim** manages duplicate variables and will not give you an opportunity to mess things up!

**Step 5: Change port 1 variable 1 to a basic variable output. Generate the code and modify calculation function/subroutines as follow:**

```
*wdot = ((*torq1) - (*torq2))/J;
*accel = *wdot;
*wdup = -(*w);
```

Note that the variable *wdup* is now known in the calculation function and we have an explicit assignment of it.

**Step 6: Using AMESim, create the system shown. Make sure you select the original submodel *RL02*. If the system is called *NAME*, AMESim will generate code called *NAME_.c*. Load this code into an editor and search for the call to the function *rl02_*.**




The code looks complex and there are special calls that deal with discontinuity handling and with linear analysis. Below is a simplified version with lines of code irrelevant for this discussion removed.

```
/* Assign the state variables y[] calculated by the integra-
      tor to the appropriate variables v[]. */

v[0] = y[0];                                  This is the state
                                              variable

/* Call submodels in the order that ensures the input
    requirements of each submodel are satisfied. */

t000_(&n);

v[3] = -v[0];                                 This is the sign
                                              reversed duplicate

rdam0_(&n, &v[3], &v[6], &v[5], r2);          Rotary damper

v[2] = v[6];                                  This is a simple
                                              duplicate associa-
                                              ted with RDAM0

w000_(&n);
                Rotary inertia
rl02_(&n, &v[2], &v[0], &dot[0], &v[1], &v[4], r1, J1);
```

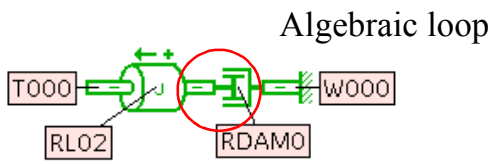
The important thing is the duplicate variables are taken out of the parent submodels and become submodels in their own right. **AMESim** includes the duplicate variables with the submodels into a calling sequence. Note that:

> The **reversed sign duplicate** is ‘called’ **before** its parent submodel and several other submodels are called between them. This is the feature that makes duplicates useful.
>
> The **simple duplicate** associated with *RDAM0* is called **after** its parent submodel. It is not useful in this system but could be very useful in other systems.

**Step 7: Change *RL02* to *RL50*. Go to *Parameter* mode and reload the code generated by AMESim into an editor.**

Note that when **AMESim** regenerated the code it indicated there was an implicit variable. Your new submodel certainly did not declare an implicit state or a constraint. The only possible way this variable is created is by an **implicit** or **algebraic loop**.

```
Creating a simulation program for your system
Number of states    1
Number of implicits 1
```



When you examine the code created by **AMESim**, you will find the code is more complex. Previously the **LSODA** integrator was used and now it is the **DASSL** integrator. Stripping irrelevant lines of code the structure is as follows:

```
/* Assign the state variables y[] calculated by the integra-
   tor to the appropriate variables v[]. */

  v[0] = y[0];
  v[2] = y[1];   <-- y[0] is the explicit state and y[1] is a constraint introduced
                     by AMESim to resolve the algebraic loop.

/* Call submodel in the order that ensures the input
   requirements of each submodel are satisfied. */

  t000_(&n);

  w000_(&n);      Call to rotary inertia uses integrator estimate v[2] for torque
                  produced by damper

rl50_(&n, &v[3], &v[2], &v[0], &dot[0], &v[1], &v[4], r1, J1
    );            Rotary damper produces its own estimate v[6] which is
                  probably different

rdam0_(&n, &v[3], &v[6], &v[5], r2);

v[2] = v[6];      This is the simple duplicate associated with RDAM0.
                  v[2] and v[6] are the same.
delta[1] = v[2] - y[1];
                  This is the error and the DASSL integrator must try to make it zero.
```

Remember:

> **AMESim uses the submodel as the basic unit with which it works. It never looks inside the submodel.**

Without the special constraint variable introduced by **AMESim**, it was impossible to call *rl50_* or *rdam0_* but this solution adds complexity and the original *RL02* is better.

**Duplicate variables, one-line macros and multi-line macros are submodels in their own right.**

# 4.4 A submodel of an ideal crank

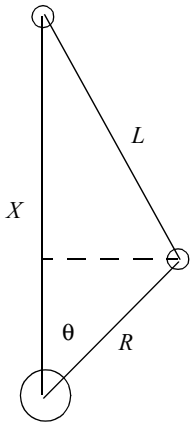
### Objectives

- to create a simple submodel of a ideal crank
- to show its capacity for creating algebraic loops
- to use one-line and multi-line macro variables to improve it.

There is in the **Mechanical** library a crank icon and an associated submodel *CRANK0*. This tutorial example follows the historical evolution of this submodel.

The diagram above shows the geometry of the crank. The radius of the crank is $R$ and the length of the connecting rod is $L$.

**Figure 4.59: Geometry of the crank**




A little bit of elementary trigonometry gives

$$X = R\cos(\theta) + \sqrt{L^2 \angle R^2 \sin^2(\theta)}$$

$X$ varies with the angle and we have

$$L \angle R \le X \le L + R$$

We introduce an offset

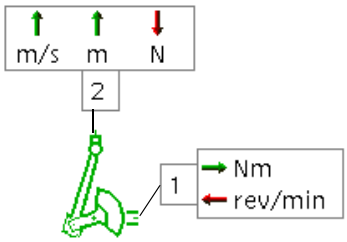
$$x = X \angle L + R = R\cos(\theta) + \sqrt{L^2 \angle R^2 \sin^2(\theta)} \angle L + R$$

with x the displacement at port 2, so that

$$0 \le x \le 2R$$

This gives us the basic equation with which we will work. We introduce the external variables for a 2 port submodel.

**Figure 4.60: External variables of the crank**



In addition we clearly need θ as an internal variable. We can now start to write equations:

$$\frac{\delta\theta}{\delta t} = \omega$$

$$x = X \angle L + R = R\cos(\theta) + \sqrt{L^2 \angle R^2 \sin^2(\theta)} \angle L + R$$

$$v = \frac{\delta x}{\delta t} = \angle \omega R \sin(\theta)\left[1 + \frac{R\cos(\theta)}{\sqrt{L^2 \angle R^2 \sin^2(\theta)}}\right]$$

and since for our ideal crank $\omega T = Fv$ we have

$$T = \frac{Fv}{\omega}$$

but we do have a problem when $\omega = v = 0$ so there is an alternative form

$$T = \angle FR \sin(\theta)\left[1 + \frac{R\cos(\theta)}{\sqrt{L^2 \angle R^2 \sin^2(\theta)}}\right]$$

Note that the crank is an example of a transformer converting between rotary and linear motion. We could introduce a transformer ratio as follows:

$$T_{rat} = \angle R \sin(\theta)\left[1 + \frac{R\cos(\theta)}{\sqrt{L^2 \angle R^2 \sin^2(\theta)}}\right]$$

so that we have $T = FT_{rat}$ and $v = \omega T_{rat}$.

### Step 1: In AMESet select the crank icon and request a new submodel.

Note that port 1 is a rotary port and port 2 a linear port.

### Step 2: Define the external variables on port 1 as follows:

| Field | Variable 1 | Variable 2 |
|---|---|---|
| Type | basic variable (output) | basic variable (input) |
| Title | torque at port 1 | angular velocity at port 1 |
| Unit | Nm | rev/min |
| name | torq | omega |

Note that, just in time, we remembered that the *t* is reserved for time and hence we used *torq*. **AMESet** would **not** have allowed us to save the submodel with a variable named *t*.

### Step 3: Define the external variables on port 2 (which is the linear port) as follows:

| Field | Variable 1 | Variable 2 | Variable 3 |
|---|---|---|---|
| Type | basic variable (output) | basic variable (output) | basic variable (input) |
| Title | velocity at port 2 | displacement at port 2 | force at port 2 |
| Unit | m/s | m | N |
| name | vel | x | force |

**Step 4: Define two internal variables as follows:**

| Field | Internal Variable 1 | Internal variable 2 |
|---|---|---|
| Type | explicit state | basic variable |
| Title | angular position of crank | transformer ratio |
| Unit | degree | m |
| name | theta | tfratio |
| derivative name | dtheta | - |
| Min. | -1000 | - |
| Default | 0.0 | - |
| Max. | 1000 | - |

**Step 5: Define two real parameters as follows:**

| Field | Parameter 1 | Parameter 2 |
|---|---|---|
| Title | stroke of crank | length of crank shaft |
| Unit | mm | mm |
| Variable name | stroke | L |
| Min. | 1 | 2 |
| Default | 30 | 50 |
| Max. | 1000 | 2000 |

Note we use stroke rather than radius because this is a more usual engineering term. The radius is clearly half the stroke. We can still use the radius by introducing a real store.

**Step 6: Specify 1 real store. Ensure the *Convert units to SI* box is ticked.**

### Step 7: Save as *CRANK5* and generate the code.

### Step 8: Edit the generated code as follows:

1. In the check statements section of the initialization function/subroutine:

```
C >>>>>>>>>>>>Initialization Function Check Statements.
      if(L .le. stroke/2)then
        print*,'Connecting rod length must be greater than stoke/2'
          error = 2
      endif
C <<<<<<<<<<<<End of Initialization Check Statements.
      if(error .eq. 1)then
```

1. In the executable statements section of the initialization function/subroutine:

```
C >>>>>>>>>>>>Initialization Function Executable Statements.
C     Set crank radius
      c(1) = stroke/2
C <<<<<<<<<<<<End of Initialization Executable Statements.
```

2. In the declaration statements section of the calculation function/subroutine:

```
C >>>>>>>>>>>>Extra Calculation Function Declarations Here.
      double precision sint, cost, root
C <<<<<<<<<<<<End of Extra Calculation declarations..
```

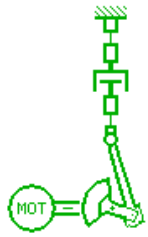
3. In the executable statements of the calculation function/subroutine:

```
C >>>>>>>>>>>>Calculation Function Executable Statements.
C Set common quantities

      sint = sin(theta)
      cost = cos(theta)
      root = sqrt(L*L - c(1)*c(1)*sint*sint)

C Set transformer ratio and hence the torque and linear velocity

      tfratio = -c(1)*sint*(1.0d0 + c(1)*c(1)*sint*sint)
      torq    = tfratio*force
      vel     = tfratio*omega

C Set linear displacement

      x = c(1)*cost + root -L + c(1)

C Set derivative of rotary speed

      dtheta = omega
C <<<<<<<<<<<<End of Calculation Executable Statements.

C     SI -> Common units conversions.
```

**Step 9: Compile the new submodel and debug as necessary.**

**Step 10: Test the new submodel in AMESim with the following system. use all default values and run the simulation with a final time of 1 second.**

**Figure 4.61: System for testing the crank submodel.**




The interesting point is the following information in the *System compilation* dialog box:

**Figure 4.62: AMESim detects an implicit loop.**

```
Creating a simulation program for your system
Number of states   1                                Terminated
Number of implicits 1
```

Where did the one implicit variable come from? The answer is from another algebraic loop! Create a *State Count* dialog box to find out what it is.

**Figure 4.63: State count dialog box**

Summary of which state variables controlled the integration step size

| State No | Controlled | Submodel | Variable | Unit |
|---|---|---|---|---|
| 1 | 0 | CRANK5-1 | angular position of crank | degree |
| 2 | 0 | DAM000-1 | force at port 1 | N |

Remember AMESim tries to sort the submodels into a calling sequence so that as each submodel is called, all its inputs are known. In this case it is impossible:

- We cannot call the damper submodel *DAM000* and calculate the force output until the velocity input is provided by *CRANK5*.
- We cannot call *CRANK5* to calculate this velocity until the force is provided by *DAM000*.

AMESim breaks the deadlock by making either the force or the velocity a special constraint variable and using a generalized Newton method to solve for it. In Figure 4.63 it is the force but in your case it could be the velocity. This can depend on the order in which you added the components to the sketch.

The system normally works OK with its algebraic loop but there can be a slight loss in speed and reliability.

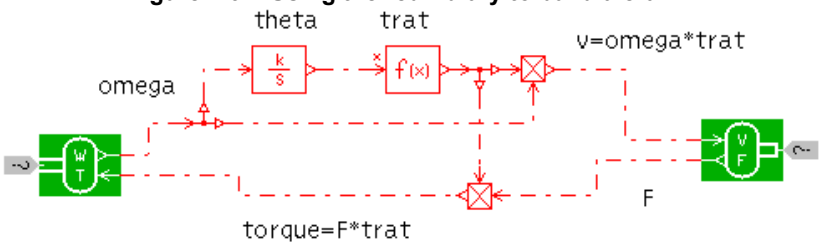
Remember that state variables are calculated by the integrator and not by the submodels. It follows that the crank angle θ is available. Hence the outputs on port

1 of *CRANK5*, *v* and *x*, can be calculated freely. It follows that the input velocity for *DAM000* is known and there is no need for the algebraic loop at all! Remember the following statement:

> **AMESim uses the submodel as the basic unit with which it works. It never looks inside the submodel.**

One possible solution is to split up the submodel into two or more parts. To take this to an extreme we could build a supercomponent as follows:

**Figure 4.64: Using the red library to build a crank.**




This ignores the displacement but even that could be calculated if really needed. We could associate this with a crank icon. We could even customize it with **AMECustom** to make it appear similar to *CRANK5*.

However, **AMESim** provides another solution. We would like to extract some of the equations from *CRANK5* and allow them to behave like submodels in there own right. This is precisely what we do.

There are three ways of extracting equations from **AMESim** submodels:

- duplicate variables (simple or reversed sign) which you have seen already;
- one-line macros;
- multi-line macros.

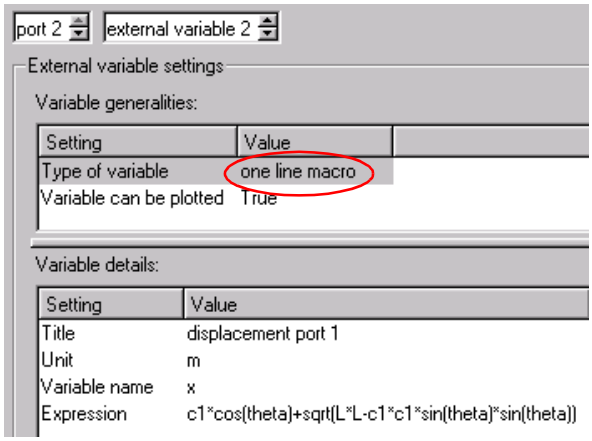
### Step 11: If necessary, reload *CRANK5*

### Step 12: File ▶ Save as specifying *CRANK6*

We have decided that there would be big advantages to extracting the calculation of the linear velocity from *CRANK5*. We might as well extract the displacement as well. If the damper had needed the displacement, this would have contributed to the implicit loop.

### Step 13: Load the details of port 2 external variable 2 specifying the linear displacement. Change this to a one-line macro as follows:

**Figure 4.65: Change the value to a one-line macro**




The one-line macro is a ‘light weight’ version of the multi-line macro. We must define the expression in a single line. The expression can contain the following:

- suitable variables referenced by their name (*theta* in the current example);
- suitable real parameters referenced by their name (*L* in the current example);
- real stores references by *c1*, *c2*, etc. (*c1* in the current example);
- normal arithmetic operators like +, -, * ,/ and also ** and ^ for raised to the power (be careful if your keyboard supports ^ as in â: it is safer to use **);
- parenthesis with their usual mathematical significance;
- *pi* which is taken to be π;
- simple mathematical function of one variable (*sin* and *cos* in the current example).
- *t* which is taken to be time.

Now we must define what we mean by an appropriate variable. It is easier to say what variables are not allowed:

- a variable cannot be defined in terms of itself;
- basic variables which are outputs are not allowed,
- duplicate variables are not allowed,
- variables with dimension greater than 1 are not allowed.

These rules appear to be somewhat arbitrary. To understand why they exist, it is interesting to see how the one-line macro works. If we saved *CRANK6* in its present state and used it in a simulation, the code generated by **AMESim** would included a line like:

```
v[4]  = c1[0]*cos(v[5]*1.74532925199433e-02)+sqrt(r1[0]*r1[0]-c1[0]*c1[0]
        *sin(v[5]*1.74532925199433e-02)*sin(v[5]*1.74532925199433e-02));
```

This is similar to our one-line macro expression and if it had been

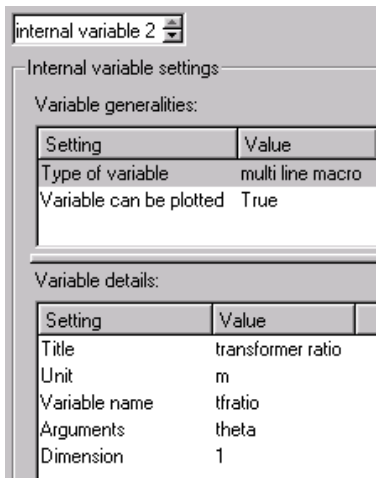
```
v[4]  = c1[0]*cos(v[5])+sqrt(r1[0]*r1[0]
        -c1[0]*c1[0]*sin(v[5])*sin(v[5]));
```

it would have had exactly the same structure as the expression. The difference is there because we asked for conversion to SI units. The variable *theta* which corresponds to *v[5]* is in degrees. **AMESet** has put a factor in to convert to radians. This enables us to think in SI units in **AMESet** but have the convenience of common units.

Also in the generated code is a call to the submodel function *crank6_*. Think of one-line macros as a slightly more complex version of duplicate variables. If we get a few other calls between the one-line macro and *crank6_*, we may break an algebraic loop. However, it is not enough in the current case.

### Step 14: Take the transformer ratio which is internal variable number 2 and modify as follows:

**Figure 4.66: A multi-line macro.**

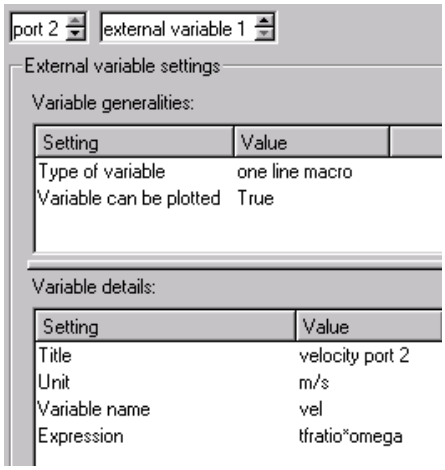



What is a multi-line macro? In simple terms it is like a one-line macro but with the possibility of more than one line of code. You can also call any function you have access to including the full range of **AMESim** utility functions.

Instead of an *Expression* field there is an *Argument* field. In this field you give a list of variables on which the multi-line macro depends referenced by their names and separated by blanks and/or commas. Restrictions are the same as with one-line macros.

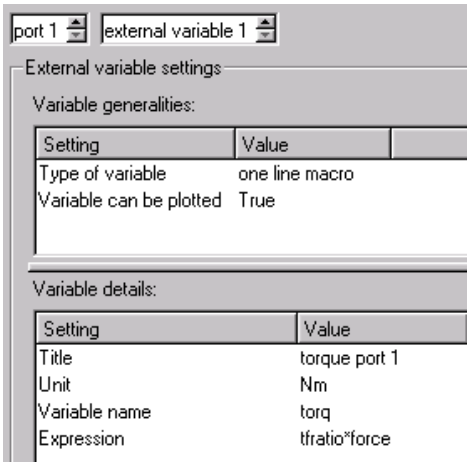
### Step 15: Take the linear velocity which is port 2 variable 1 and modify as follows:

**Figure 4.67: Velocity as a one-line macro.**




### Step 16: Take the torque which is port 1 variable 1 and modify as follows:

**Figure 4.68: Torque as a one-line macro.**




### Step 17: Generate code and load into an editor.

First note that a double precision (double in C) function has appeared in which we must define *tfratio*. This function has a section where we can make declarations and another where we insert executable statements. Note

- **The multi-line macro variable function/subroutine is like the calculation function/subroutine except that it returns a value.**
- **It has access to all the same real, integer and text parameters and real and integer stores.**

- **If the *Submodel requires time* box is ticked, it has access to *t*.**
- **If the *Submodel requires discontinuity flag* box is ticked, it has access to *flag*.**

In the *crank6* subroutine (or *crank6_* function) the definitions of the three one-line macros must be removed since these will be written separately by **AMESim**. Code for *tfratio* will be moved from *crank6/crank6_* to *crank6_macro0/crank6macro0*.

### Step 18: Move relevant code into the multi-line macro.

We have the declarations as follows:

```
      external distim
C >>>>>>>>>>>>Extra Macro Function tfratio Declarations Here.
      double precision sint, cost, root
C <<<<<<<<<<<<End of Extra Macro tfratio declarations.
      integer loop
```

and executable statements as follows:

```
C >>>>>>>>>>>>Macro Function tfratio Executable Statements.
C Set common quantities

      sint = sin(theta)
      cost = cos(theta)
      root = sqrt(L*L - c(1)*c(1)*sint*sint)

C Set transformer ratio.

      tfratio = -c(1)*sint*(1.0d0 + c(1)*c(1)*sint*sint)
C <<<<<<<<<<<<End of Macro tfratio Executable Statements.
```

### Step 19: Remove unnecessary code from *crank6/crank6_*.

The declaration section now contains nothing.

```
C >>>>>>>>>>>>Extra Calculation Function Declarations Here.
C <<<<<<<<<<<<End of Extra Calculation declarations.
```

The executable statement contains only the assign of the *dtheta*.

```
C >>>>>>>>>>>>Calculation Function Executable Statements.

C Set derivative of rotary speed

      dtheta = omega
C <<<<<<<<<<<<End of Calculation Executable Statements.
```

**Step 20: Compile and debug the submodel. Take your system containing the crank and replace *CRANK5* with *CRANK6* and verify the algebraic loop disappears.**

We can now see how the multi-line macro and two one-line macros are treated like submodels avoiding the algebraic loop.

```
/* Assign the state variables y[] calculated by the integrator
   to the appropriate variables v[]. */

v[5] = y[0];                                  The state variable from the integrator

/* Call submodel calculation subroutine in the order
that ensures the input requirements of each submodel
are satisfied. */

pm000_(&n);                                   The one-line macro for x only uses the
                                              state variable which is v[5]
v[4] = c1[0]*cos(v[5]*1.74532925199433e-02)+sqrt(r1[0]*r1[0]-
     c1[0]*c1[0]*sin(v[5]*1.74532925199433e-02)
     *sin(v[5]*1.74532925199433e-02));

v[6] = crank6_macro0_(&n, &v[5], r1, c1, J1, &t);   The mult-line macro for tfratio
                                                    only requires the state variable v[5]

v[3] = v[6]*v[1]*1.0471975511966e-01;         The one-line macro for v uses tfratio
                                              which is v[6]

dam000_(&n, &v[3], &v[7], r2);¶               The damper

v[2] = r2[0]*(v[3]+v[7]);
v[8] = r2[0]*(v[3]+v[7]);                     Two one-line macros associated with the damper

crank6_(&n, &v[1], &v[2], &v[5], &dot[0], &v[6], r1, c1, J1, &t);   The crank

v[0] = v[6]*v[2];                             One-line macro for torq
```

This gives some ideas of how macro variables can be used to break algebraic loops but a few words of advice:

- **Do not over use macro variable.**
- **Start by constructing submodels in a very simple way. It is much easier to debug a submodel that does not contain macros.**
- **Only introduce macro variables if there are good reasons for doing so. This usually means a tendency to produce algebraic loops.**
- **Transformers in particular benefit from macro variable.**

# 4.5 Line submodels

Hydraulic, pneumatic and any other lines are a little different from other **AMESim** components. There is no special category in **AMESim** from which they can be selected and their icon is not fixed. Its size and shape are determined when the line is drawn.

To enable submodels of lines to be constructed in **AMESet**, a special category for lines appears at the top of the other categories.

This produces a small collection of specific icons. You use these just like any other specific icons.

**Note that all line submodels have two ports**.

# 4.6 Avoiding algebraic loops

The concept of the algebraic loop was introduced in this chapter. Briefly there is an algebraic loop when there is no order in which the submodels can be called such that all the inputs of each submodel are known when the submodel is called. **AMESim** overcomes this problem by introducing implicit variables to break the algebraic loop. The result is differential algebraic equations but they are generally easy to solve using the *DASSL* integrator. Technically d.a.e.s are classified by an integer known as the **index of nil-potency** or simply **index**. Algebraic loops generate index 1 d.a.e.s which are the easiest to solve whereas the zero mass submodel, *MAS000* described in section 2.10, results in an index 2 problem which is significantly more difficult. The infinite stiff spring submodel *SPR1* is similar whereas the differentiator submodel *DIF00* gives rise to an index 1 problem.

To summarize there are two types of implicit variables:

- Implicit variables declared in submodels as **constraints** or **implicit states**. These usually result in index 1 or 2 d.a.e.s.
- Constraints created by **AMESim** to resolve algebraic loops normally resulting in index 1 d.a.e.s.

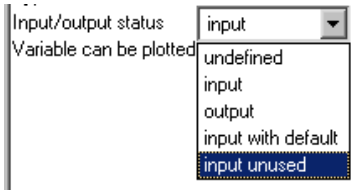
The ordinary differential solver used in **AMESim** is generally more reliable than the d.a.e. solver. However, there is no point becoming pathological about d.a.e.s. The best advice for submodel writer is to seek to reduce the number of implicit variables rather than totally eliminate them. This can be done by observing two rules.

1. Introduce declared implicit states and constraint variables in submodels sparingly and only when there is a genuine need. Warn users in the text of the description section of the code of the problems that can arise using these submodels.

2. Construct all submodels in a way that minimizes the chances of algebraic loops with generated implicit variables.

To expand the second rule:

- **Explicit states, fixed variables, implicit states and constraint variables as external variables are extremely useful. Never have an useful variable like this as an internal variable and make a copy to an external variable as a basic variable output. This is a complete waste of a useful variable.**
- **Use duplicate variables when the same variable occurs on more than one port.**
- **If you have an variable as an input to a port and it is not used in the calculation, remove it or make it an *input unused*.**




- **In difficult cases where algebraic loops are generated, consider using macro variables.**
- **Consider also a different subdivision of a subsystem into submodels with smaller units.**

# Chapter 5: Reference Guide for AMESet

## 5.1 Introduction

This chapter is designed to be used for reference from the main index. It is organized as follows:

- a description of **AMESim** nodes,
- features available from the menu bar,
- features available from the tool bar,
- facilities available in the main window including setting the characteristics of ports, parameters and variables,
- debugging submodels created in **AMESet**,
- a summary of assignments of variables.

## 5.2 AMESim Nodes

It is important to be aware of the **AMESim** nodes to be efficient in the use of **AMESet**.

An **AMESim** node is any folder or directory which is used as the root of a storage area by

- **AMESet** for generic submodels,
- **AMESim** for generic supercomponents,
- **AMECustom** for customized submodels and supercomponents.

Below is shown a typical structure of an **AMESim** node.

**Figure 5.1: AMESim node**

The folders are used as follows:

| Folder | Exists ... | Purpose |
|---|---|---|
| *submodels* | always. | Used to store details of submodels and supercomponents associated with the node |
| Icons | only if a category has been created specifically for this node. | Used to store category icons and icons of components stored in the category. |
| *lib* | only if a user creates it manually. | The preferred place to store an archive library (.a or .lib). |
| *data* | only if a user creates it manually. | The preferred place for any data files. |
| *doc* | always. | The preferred place to store any documentation files such as HTML. |

The files in the **AMESim** node are as follows:

| File | Exist ... | Purpose |
|---|---|---|
| *submodels.index* | always. | Used to associate submodels and supercomponents with icons. |
| *AMEIcons* | only if a category is created. | Used to specify the files of the category associated with the node. |
| *AME.make* | only if created manually. | Used to modify the behaviour of the facility that creates or 'makes' the executable of an **AMESim** model. |

### Files in the Icons folder

The *.xbm* files define the icons for categories. The *.ico* files define the icons for the components in the category, the icon description and the position and type of their ports.

### Files and folders in the submodels folder

**AMESet** creates:

- *.spe* files which specifies the characteristics of the submodel. These files are read by **AMESim** and specify how the call is to be made to the submodel.

- *.c* or *.f* files which are the source code of the submodels.
- *.o* or *.obj* files which are the object code of the submodels created when the source is compiled. On some platforms these are stored in a special sub-directory of *submodels* and in others directly in *submodels*.

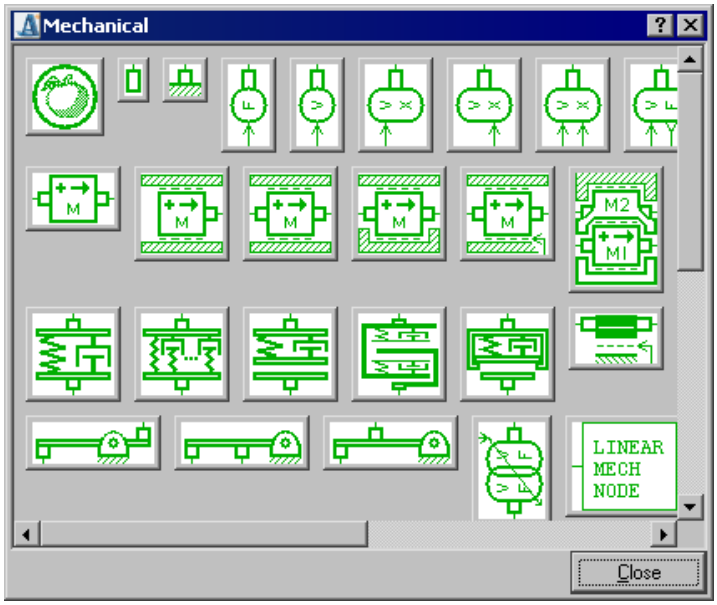
### Submodel Libraries

It is **not** a good idea to create submodels (and supercomponents) scattered around the disk system in a random fashion. Concentrate them into a small number of **AMESim** nodes grouping them together so that all objects in a node have a unifying theme. The node can then be described as a **submodel library**. All **AMESim** submodel libraries are organized in this way. Figure 5.1 is actually the **AMESim** cooling system library.

## 5.3 Using the category icons

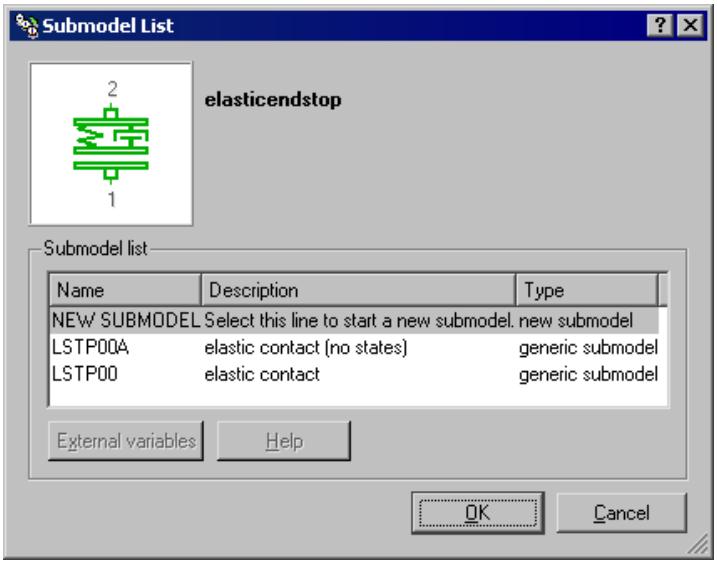
If you select a category icon you get a dialog box in exactly the same way as with **AMESim**, **AMERun** and **AMECustom**.

**Figure 5.2: The icons in the Mechanical category.**



If you click on one of the icons, you get a *Submodel List* dialog box.

**Figure 5.3: The Submodel List dialog box.**




You can select from the list an existing submodel or a new submodel with the icon associated with it.

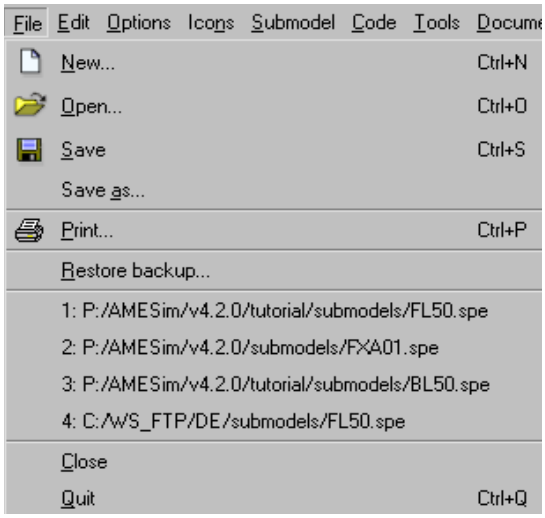
This is the most common way of initiating work on a new or existing submodels but see also "New", page 135 and "Open", page 136.

## 5.4 The AMESet menu bar

Each menu allows you to access the main **AMESet** commands. See the details in the following sections.

## 5.4.1 File menu

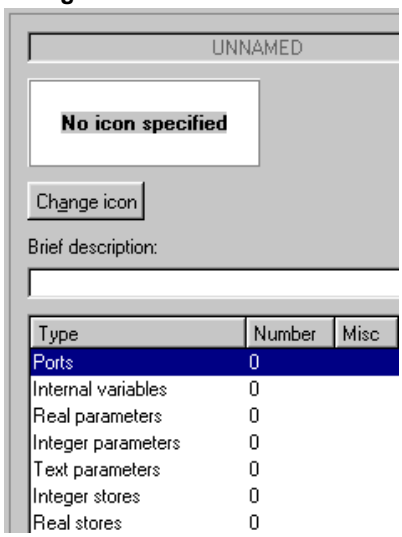
**Figure 5.4: The file menu.**




**New**

Use **File ▶ New...** to initiate the process of opening a blank submodel specification. It will not be associated with any icon and will have no proper name (Figure 5.5). The short cut is **Ctrl+N**. The facility is also available by clicking on the icon in the tool bar. See also 5.3 “Using the category icons”, page 133.

**Figure 5.5: A new submodel.**

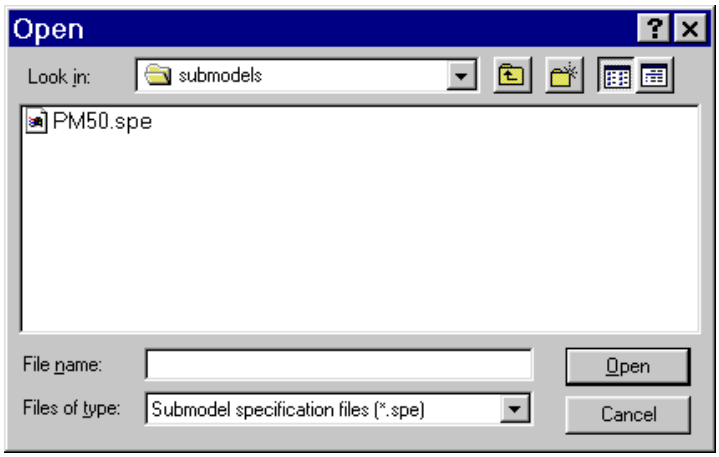


### Open

Use **File ▶ Open...** to initiate the process of opening an existing submodel. A file browser is displayed and allows you to search for the *.spe* file of an existing submodel. The shortcut is **Ctrl+O**. The facility is also available by clicking on the icon in the tool bar.

**You are searching for *.spe* files and hence you look in the submodels subdirectory of AMESim nodes.**

**Figure 5.6: Browsing for an existing submodel.**




AMESet tries to find the corresponding *submodels.index* from which it can deduce the icon to display.

**Note:** You can also specify an existing submodel by opening the appropriate category and selecting the icon with which it is associated. See 5.3 “Using the category icons”, page 133.

You can only open *.spe* files of **generic submodels**. Use AMESim to open **generic supercomponents** and AMECustom to open **customized objects**.

### Save

Use **File ▶ Save** if you want AMESet to save your complete submodel including the *.spe* file and source file. The shortcut is **Ctrl+S**. The facility is also available by clicking on the icon in the tool bar.

The source generated will be of type (C or F77) corresponding to the source type currently set. Note that you must have the appropriate write permission to save the submodel in this way. This prevents you from overwriting the supplied AMESim library submodels!

If the submodel is a new one, the **Save** facility behaves as **Save as**.

### The traffic lights

The traffic light indicates if the submodel is in a fit state to save:

If the traffic light is **green**, the setup is complete.

If the traffic light is **red**, the setup is not complete or is wrong.

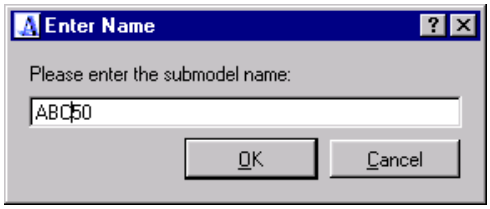
The setup can be complete and not totally wrong but some settings may not relevant or could be improved. This will not prevent the submodel from being saved but it is not totally satisfactory. In these cases, the traffic light will be **orange**.

### Save as

Select this item if you want **AMESet** to save your submodel under a new name.

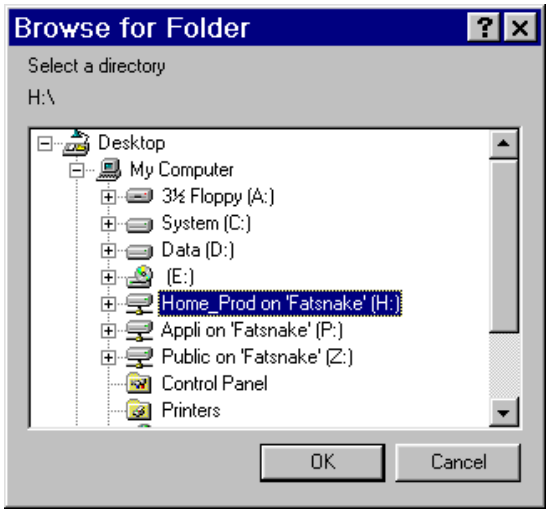
**Step 1: Select File ▶ Save as.**

You are asked to define the name. This must be unique i.e. not used by any other submodels or supercomponents.




**Step 2: Select an AMESim node where it is to be stored.**

Naturally you must have write permission.

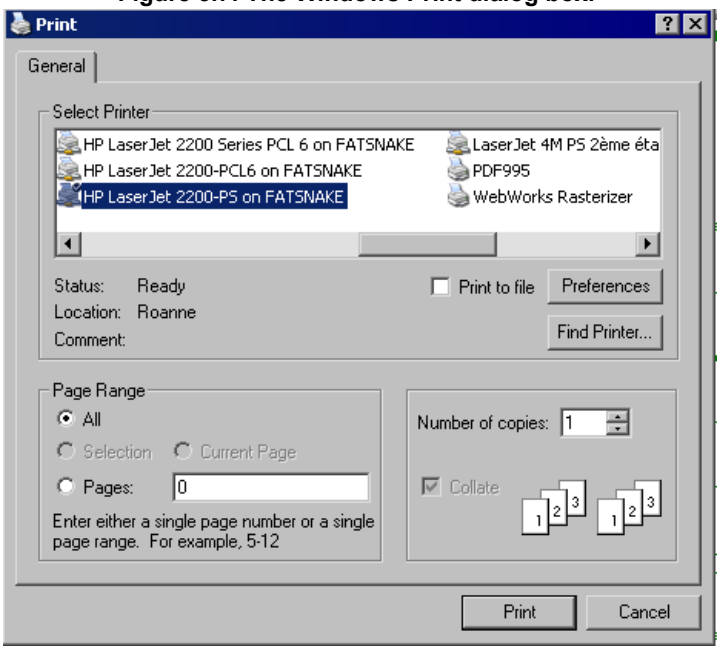



### Print

This item becomes active when a the source code of a submodel is displayed in the **AMESet** fallback editor in which case **File ▶ Print...** produces a dialog box to enable you to print the source code.

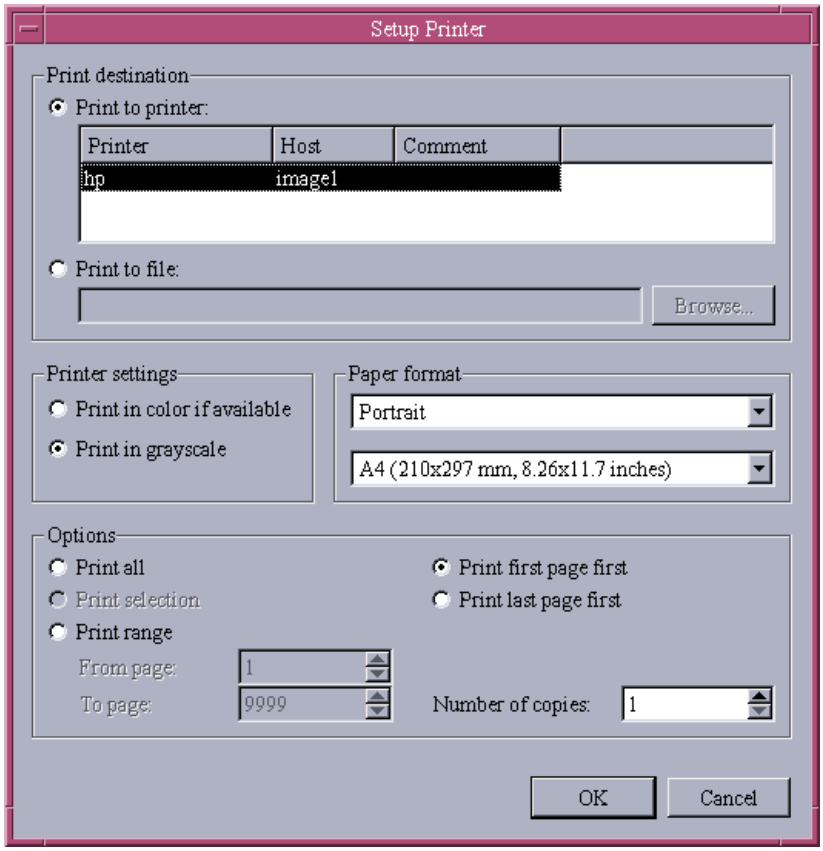
**Using Windows.**

**Figure 5.7: The Windows Print dialog box.**



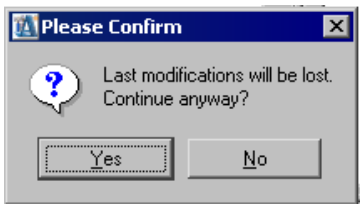
**Using Unix:**

**Figure 5.8: The Unix Setup Printer dialog box.**



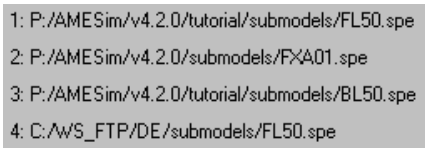

### Restore backup

When you create submodels it is not normal to get them all right at the first attempt! Hence you continue to work on them and overwrite the old source and *.spe* file with a new and hopefully better version. **AMESet** creates one level of backup when this is done. If you use **File ▶ Restore backup...** , you can restore this backup. You are asked to confirm the request.



### Last opened files list

The *File* menu displays the last opened files list. You can use the *AMESet Preferences* to indicate the number of last opened files you want to display.




### Close

Use **File ▶ Close** if you want **AMESet** to close the active submodel.

If the file is out of date, **AMESet** will ask you if you want to compile it before closing it.

### Quit

Use **File ▶ Quit** if you want to terminate the **AMESet** session. If any submodels have been changed without saving, you will be asked if you want to save them.

## 5.4.2 Edit menu

The first eight items operate on a selected or highlighted object. This may be a:

- port,
- external variable,
- internal variable,
- real parameter,
- integer parameter or
- text parameter.

For *Copy-Paste* the source and destination objects must be of the same type with the single exception that you can *Copy-Paste* between internal and external variables.

For a selected port the only operations that are allowed are *Move up* and *Move down*.

### Cut

The selected object is removed. The shortcut is **Ctrl+X**. The facility is also available by clicking on the *Cut current item* button in the toolbar.

### Copy

The selected object is copied into a special buffer or clipboard. The shortcut is **Ctrl+C**. The facility is also available by clicking on the *Copy current item* button in the tool bar.

### Paste

The contents of the selected object are overwritten with the contents of the clipboard. The shortcut is **Ctrl+V**. The facility is also available by clicking on the *Paste current item* button in the tool bar.

### Move up

If it is possible, the selected object is moved up one position in the list. The shortcut is **Ctrl+Up**. Remember that with external variables the rule:

- outputs first
- inputs next
- inputs with default last

is strictly enforced.

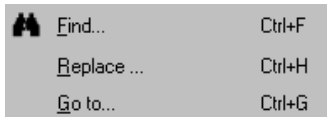
### Move down

If it is possible, the selected object is moved down one position in the list. The shortcut is **Ctrl+Down**. Remember that with external variables the rule:

- outputs first
- inputs next
- inputs with default last

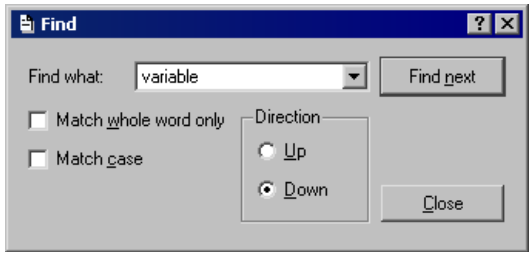
is strictly enforced.

The next three items operate on the source code displayed in the fallback editor.



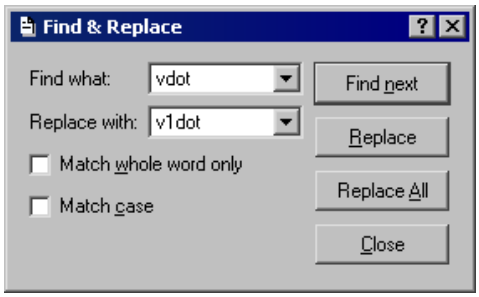

### Find

Use **Edit ▶ Find...** to look for text in the code editor. You can also use the short cut *Cntrl+F*. Enter the text you are looking for and then click on *Find next*.



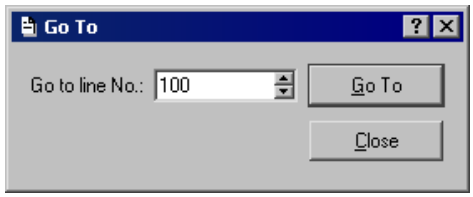
### Replace

Use **Edit ▶ Replace...** or the short cut *Cntrl+H* to replace occurrences of one text string in the code editor by another. Fill the text strings in the *Find & Replace* dialog box.

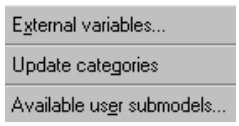



### Go to

Use **Edit ▶ Go to...** or the short cut *Cntrl+G* to scroll the code editor to a specified line. Fill the line number into the *Go To* dialog box and click to *Go To*.




The last three items in the *Edit* menu provide general useful facilities.




### View external variables

Use **Edit ▶ External variables...** to preview the external variables as they will appear in **AMESim** when the submodel is saved.

### Update categories

**Edit ▶ Update categories** starts a reinitialization of the category icons, the contents of the categories and associated data structures based on the current path list. You will see the category icons disappear and be reconstructed.

### List User Submodels

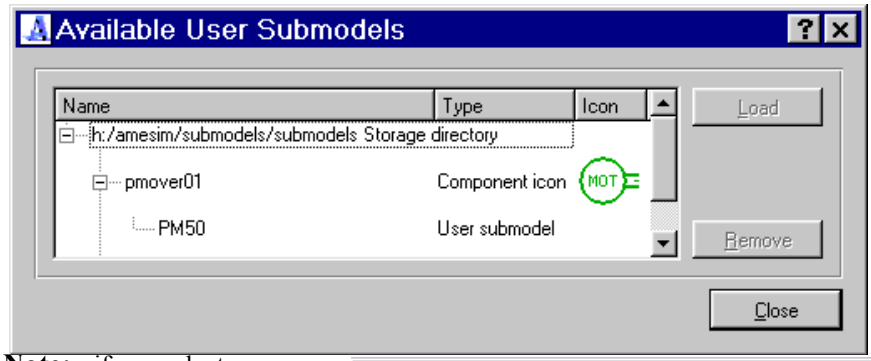
A **user submodel** is a generic submodel which is stored in an **AMESim** node which is not the *$AME* (*%AME%*) node or a sub-directory of this node. In other words it is not supplied as part of a standard **AMESim** product.

Selecting this item produces an *Available User Submodels* dialog box. The best procedure is as follows:

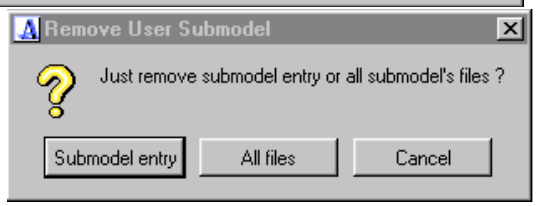
**Step 1: Adjust the path list if necessary using Options ▶ Path list.**

**Step 2: Select Edit ▶ List User Submodels.**

**Figure 5.9: The Available User Submodels dialog box.**




**Note:** if you select a submodel, the *Remove* button becomes active. If you click on this button, a *Remove User Submodel* dialog box appears. You can remove the submodel in two ways:

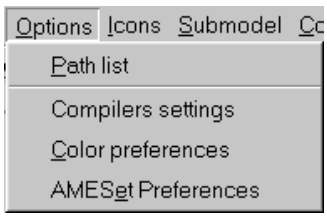



1. **Submodel entry**. The entry in *submodels.index* is removed which makes it inaccessible in **AMESim**.
2. **All files**. This removes the entry in *submodels.index* and also removes the specification *(.spe)* file. source (*.c* and/or *.f*) file, any backup (*.bak*) files of these and any object (*.o* or *.obj*) files.

If you take the first option, you can restore the submodel using **File ▶ Open** and locating and loading the *.spe* file.

If you take the second option, the files really are deleted!

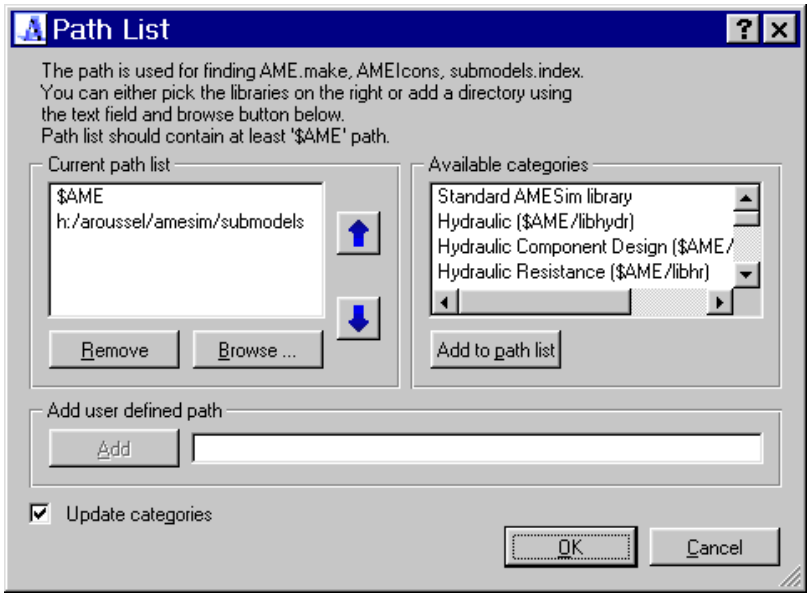
## 5.4.3 Options menu




### Path List

Select this to change the **AMESim** path list. The functionality is precisely the same as in **AMESim**.

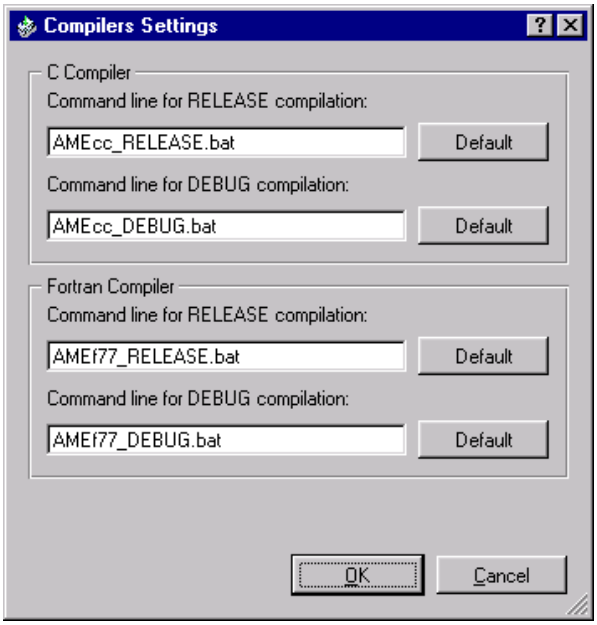
**Figure 5.10: The Path List dialog box**




## Compiler settings

If you select this item, you get a dialog box as shown below:

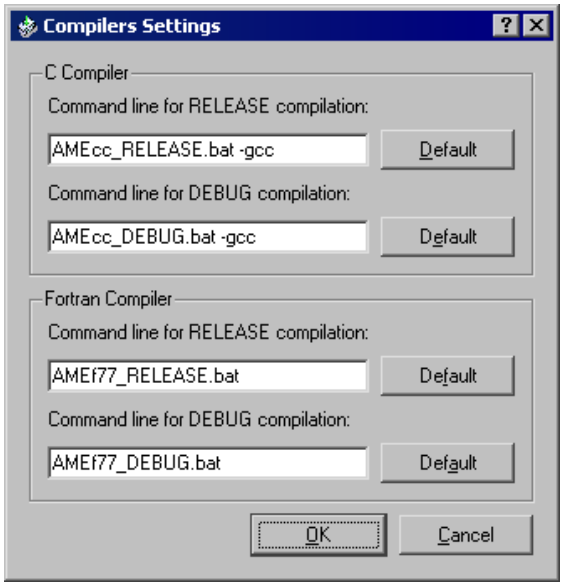
**Figure 5.11: The Compiler Settings dialog box.**



**Using Windows:**

If the **GCC** compiler is selected as default instead of Figure 5.11 you will get the following:

**Figure 5.12: The Compiler settings for GCC.**



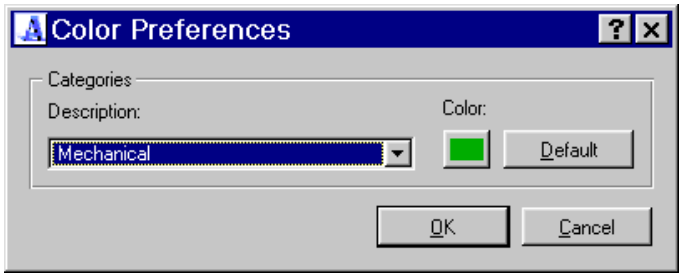

The **DEBUG** option produces code appropriate for a debugger that can understand the code produced by the compiler. The **RELEASE** option produces code which is more efficient and compact but cannot be used with a debugger. The files concerned are *.bat* files under NT and *.sh* files under Unix. Probably the supplied files are all that is needed for 99% of users. If you really do want to change them, copy them from the $AME system folder to another suitable folder and modify them. Insert the name(s) into the appropriate slots and check that your modifications work.

**You can enter the full pathname of this executable or you can enter just the executable name provided the path environment variable is set so that it can be found.**

## Color preferences

This is exactly the same utility as in **AMESim**, **AMERun** and **AMECustom**. It is useful when you create a new category. **AMESet** will display it initially in grey. Use *Color preferences* to set a different color.

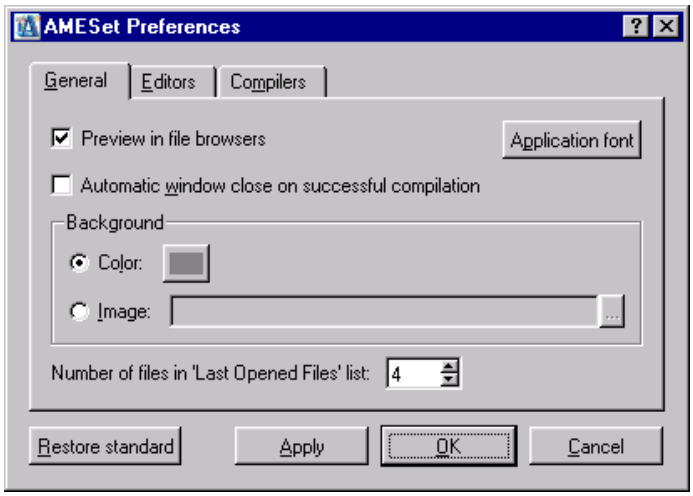
**Figure 5.13: The Color Preferences dialog box.**




## AMESet preferences

Selecting this produces a *AMESet Preferences* dialog box.

**Figure 5.14: The General tab for AMESet Preferences.**




Note the whatever changes have been made you can always click on *Restore standard*.

Options are grouped under three tabs.

### General

The *Preview in file browsers* check box applies to the *Background* area when the *Image* button is selected.

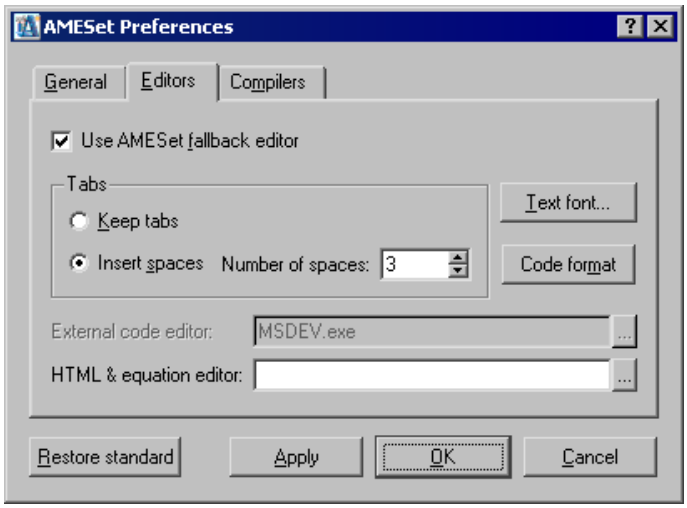
The *Application font* button allows you to select the font to be used by **AMESet**.

You can change the background color of **AMESet** or use an image for it, with the *Color* and *Image* radio buttons.

The function of the other facilities is obvious from their titles.

### Editors

**Figure 5.15: The Editor tab for AMESet Preferences.**




If you are using **AMESet** for the first time, **AMESet** will use a built-in editor known as the **fallback editor**. It was originally intended that this editor would be rarely used and so it was kept very simple. However, experience has shown that it is extremely convenient to work entirely within **AMESet** and hence it is now much more powerful.

On the other hand, users have very individual tastes and preferences concerning editors and if you want to use another editor, it is very easy to change. Use the following procedure.

**Step 1: Disable (untick) the *Use AMESet fallback editor* check box.**

**Step 2: Enter the name of the editor executable you wish to use.**

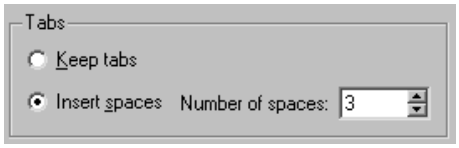
You can enter the full pathname of this executable or you can enter just the executable name provided the path environment variable is set so that it can be found. Alternatively you can use the browse button to search for it.

In this tab, you can also select the HTML editor you wish to use from **AMESet**.

If the fallback editor is enabled;

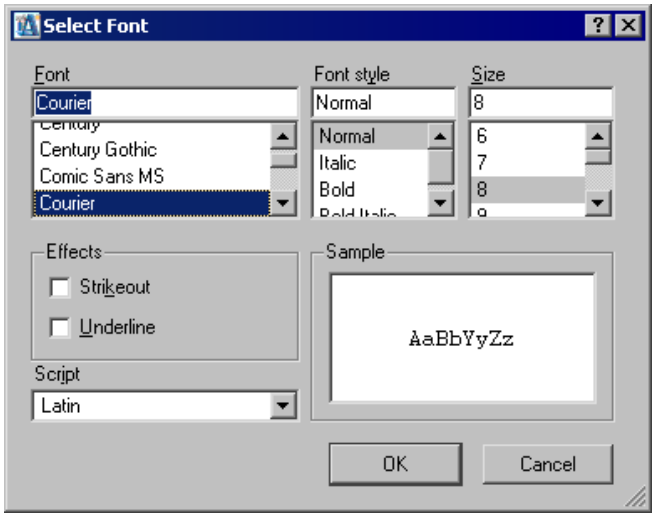
- Two radio buttons control what the tab key does.

  If *Keep tabs* is enabled, an invisible tab character is inserted into the text and the delete key removes it. If *Insert spaces* is enabled, the specified number of spaces is inserted and the delete key will remove one space.



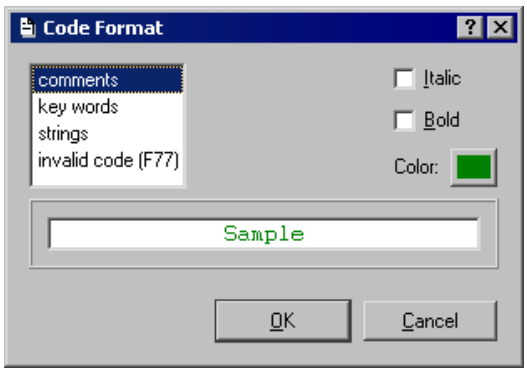

- Clicking on *Select font...* button creates the *Select Font* dialog box as shown in Figure 5.16. Use this to select a font for the text appearing in the editor.

**Figure 5.16: The Select Font dialog box.**




- Clicking on *Code format...* produces the *Code Format* dialog box as shown in Figure 5.17. Use this to employ colors and styles for the selected item and make the structure of the code clearer.

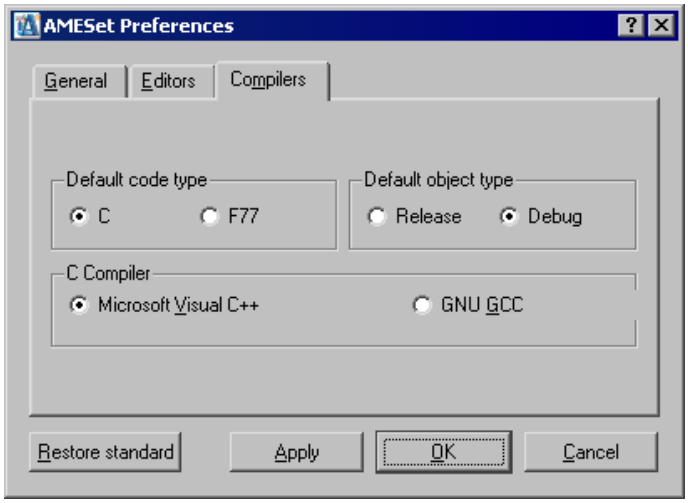
**Figure 5.17: The Code Format dialog box.**



### Compilers

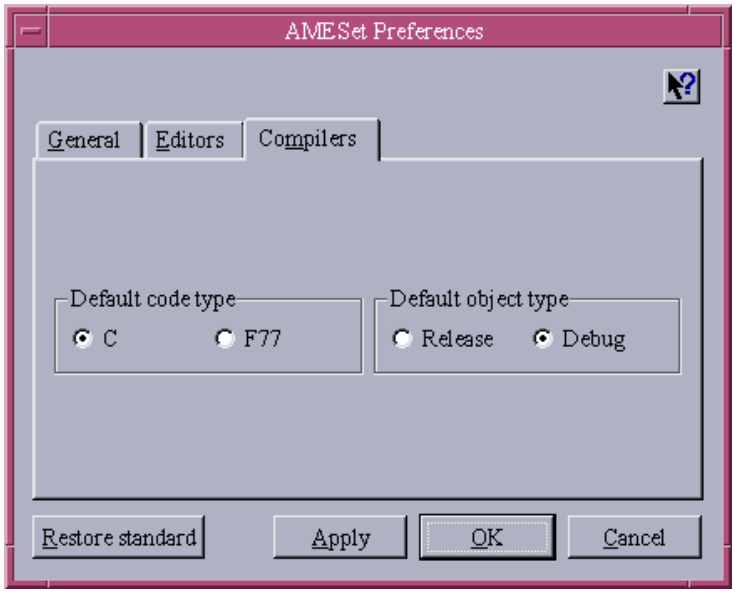
**Using Windows.**

**Figure 5.18: The Compilers tab for AMESet Preferences.**




**Using Unix.**

**Figure 5.19: The Compilers tab for AMESet Preferences.**




**AMESet** needs a compiler to produce object files for submodels. Under this tab you can select *C* or *F77* and *Release* or *Debug*. See also section 5.4.6 Code menu.

**Using Windows:**

**AMESet** provides **GCC** as a free compiler. You may also use the **Visual C++** compiler.

**Changing the default compiler:**

Do the following:

1. Go to **Options ▶ AMESet Preferences**.

   The *AMESet Preferences* dialog box appears.
2. Select the tab *Compiler*.
3. Click on the radio button for the compiler of your choice.
4. Click on the *OK* button.

**What about the user submodels?**

If you want to change the compiler and you have created your own submodels, you must recompile all your submodels and libraries with new using the batch command files (*AMEcc_Debug.bat* and *AMEcc_Release.bat*).

## 5.4.4 Icons menu

### Add category

If you do not want to use a category icon in the supplied **AMESim** libraries, you must create your own component icon. This must be stored in your own category icon. Category icon are the ones you see at the left side of the **AMESet** window.

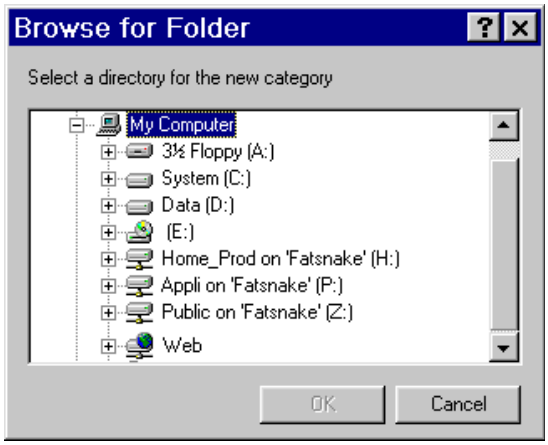
The steps involved in creating a new category icon are the following:

1. Select **Icons ▶ Add category**.

   A browser appears.

2. Select a directory for your category.

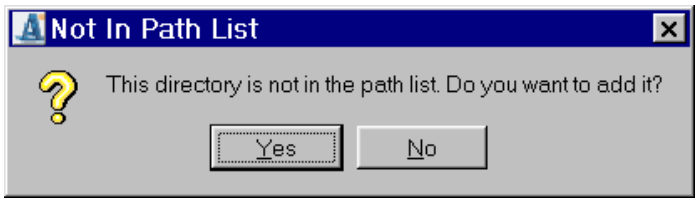
**Figure 5.69: Browsing for a Folder for an AMESim category.**




3. Click on *OK*.

   If the selected directory is not in the **AMESet** path list, the following dialog box is produced:

**Figure 5.70: Adjusting the Path List.**




   You can then update your path list and you will be asked for the category name and description. As soon as the description is validated, the *Icon Designer* appears. You can now create an icon for the new category.

### Remove category

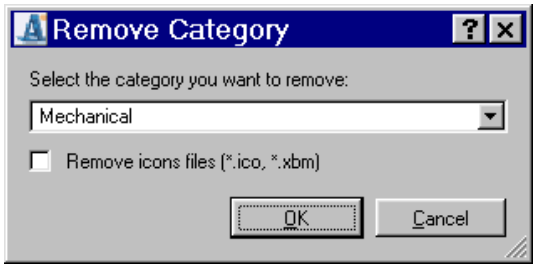
To be able to remove a category

- you must have write permission for the appropriate *.xbm* and *.ico* files to do the removal and write permission for the appropriate *AMEIcons* file to modify it,
- there must be no component icons in the category.

1. Select **Icons ▶ Remove category**.

   The *Remove Category* dialog box appears:

**Figure 5.71: Removing a Category.**



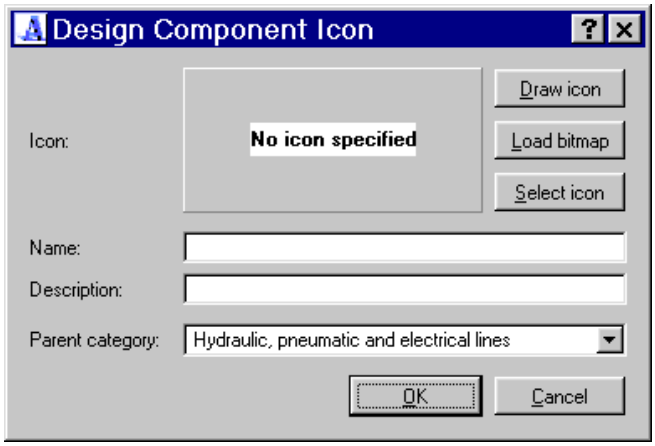

2. Select the category you want to remove.
   - Check the box *Remove icons files* if you want to remove also the files of the icon (.ico, .xbm).

### Add component

## Step 1: Create a new component

1. Use **Icons ▶ Add component**. The dialog box shown in Figure 5.1 is displayed:

**Figure 5.1: Adding a New Component Icon.**




2. Fill in the *Name*, *Description* and *Parent category* fields to give the necessary information on your new icon.

## Step 2: Specify an icon for the new component.

There are 3 different ways to assign an icon:

- **Draw a new icon:** Click on the *Draw icon* button to produce the *Icon Designer*. Design the icon and set its ports: please refer to the **AMESim** manual section 6.5.2.Creating a supercomponent icon (step 1 to step 6) to learn how to create an icon and add ports to it. Finally click on the *Save icon to*

*AMESim files* button of the *Icon Designer* dialog box.

- **Load a bitmap from a file:** A file browser allows you to load a bitmap from a file.
- **Select an existing icon from another category:** Select the icon you want within a list of existing icons.

When you have designed the icon and set its fields properly, click on the *OK* button.

### Remove component

To be able to remove a component icon:

- you must have write permission (for the *.ico* file) to do the removal,
- there must be no submodel associated with the icon.

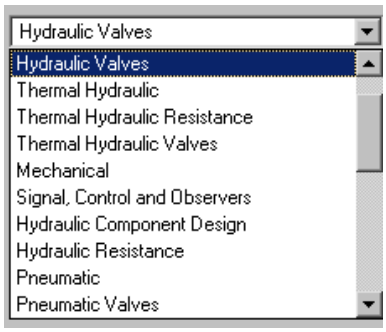
**Step 1: Select Icons ▶ Remove component.**

The *Remove Icon* dialog box appears.

**Figure 5.2: Removing a Component Icons.**

**Step 2: You can select the icon in two ways.**

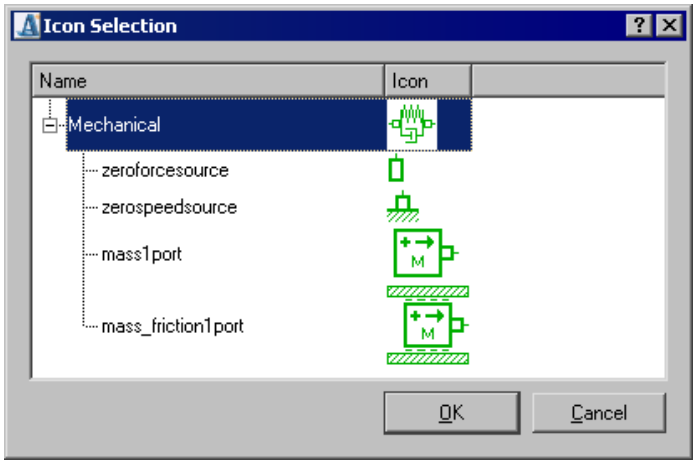
1. If you know the icon name and the category, enter the icon name and select the *Parent category*




or

2. Click on the *Select* button and click on the component icon you want to remove.

**Figure 5.3: The Icon Selection dialog box.**




### Icon designer

The Icon designer facility can be started as a general facility if you select **Icons ▶ Icon designer**. It can also be started when creating a new category icon or when creating an icon for a submodel.

With the **AMESet** *Icon Designer*, you can create and save one or more icons and specify their ports. Please refer to the **AMESim** manual section 6.5.2.Creating a supercomponent icon (step 1 to step 6) to learn how to achieve this.

### Change submodel icon

Use **Icons ▶ Change submodel icon...** if you want to replace the existing icon to which the current active submodels is associated. You can do the same thing by clicking on the *Change icon* button. In either case a *Icon selection* dialog box is created.

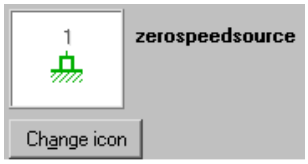
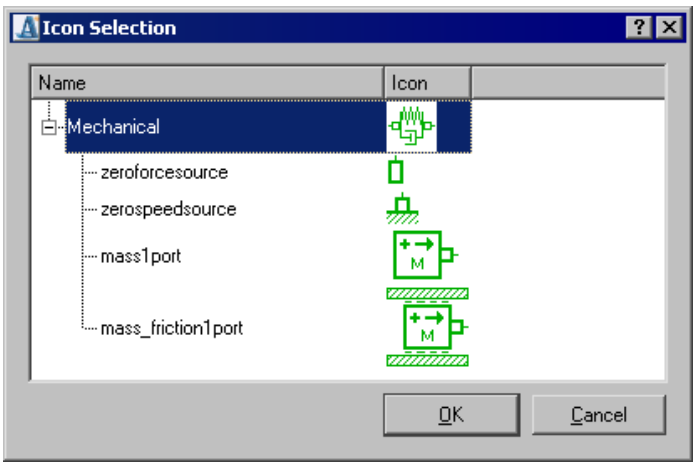


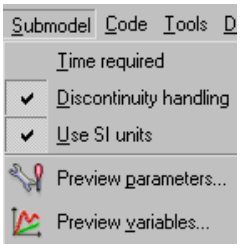

**Figure 5.4: The Icon selection dialog box.**



Expand the tree structure and select the new icon.

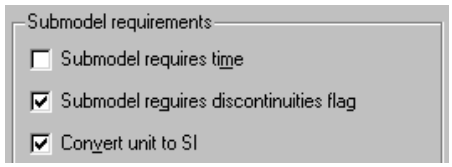
Note that you will be presented with subset of icons. They are the ones that are compatible with the active submodel. It is possible that no icons are suitable! In this case you will have to create one or adjust the submodel ports so that it becomes compatible with an existing one. Naturally you must create new icon before you attach the submodel to it.

## 5.4.5 Submodel menu




### Submodel requires time

This and the next two items can be set to true (ticked) or false (unticked). The status can also be set using the *Submodel requirements* check boxes:




If *Submode requires time* is set to true, the time variable *t* will be included in the calculation and multi-line macro functions/subroutines argument lists generated by **AMESet**.

### Discontinuity handling flag

If *Discontinuity flag required* is set to true, the *flag* variable will be included in the calculation and multi-line macro functions/subroutines argument lists generated by **AMESet**.

### Use SI units

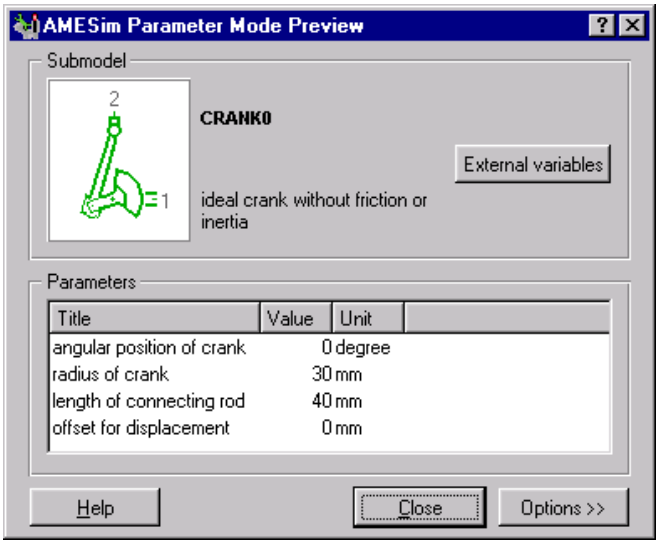
If *Use SI units* is set to true, **AMESet** will

- convert real parameters and variables to SI units on entry to any functions/ subroutines and
- convert them back to common units on exit.

### Preview submodel parameters

This shows you how the active submodel will look in the **AMESim** in the *Change parameters* dialog box. The facility is also available by clicking on the button in the tool bar. **Use this facility frequently to check that what you are getting is really what you want.**

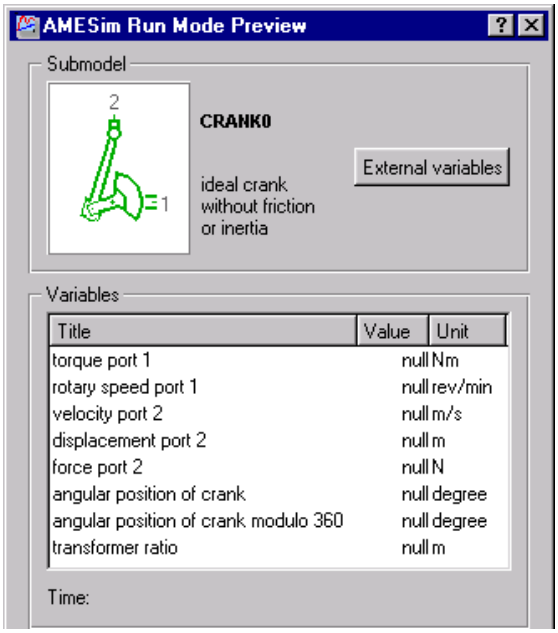
**Figure 5.5: AMESim Parameter Mode Preview.**



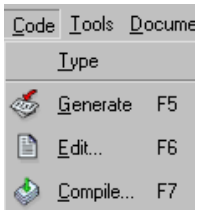

### Preview submodel variables

This shows you how the active submodel will look in the **AMESim** in the *Variable list* dialog box. The facility is also available by clicking on the button in the tool bar. box. The facility is also available by clicking on the button in the tool bar. **Use this facility frequently to check that what you are getting is really what you want.**

**Figure 5.6: AMESim Run Mode Preview.**



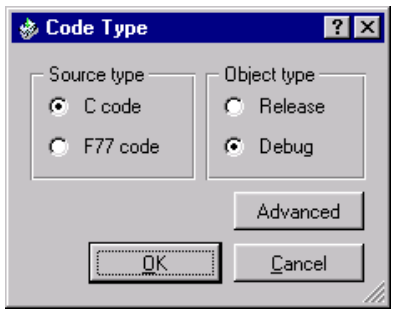
## 5.4.6 Code menu




### Type

**Code ▶ Type** allows you to select the type of source code generated (C or F77) and the type of object code generated (release or debug). **Debug** object type allows you to use a suitable debugger if you include your submodel in an **AMESim** system. **Release** object type does not.

**Figure 5.7: The Code Type dialog box.**




### Generate

Use **Code ▶ Generate** when you want to generate source code (*.c* or *.f*) for the active submodel. The specification must be complete. The facility is also available by clicking on the button in the tool bar.

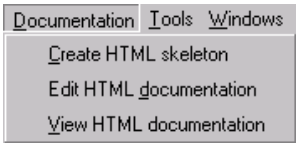
### Edit

Use **Code ▶ Edit** when you want edit the code of the current submodel. The facility is also available by clicking on the button in the tool bar.

### Compile

Use **Code ▶ Compile** when you want to compile the code of the current submodel. The facility is also available by clicking on the button in the tool bar.

## 5.4.7 Documentation menu




### Create HTML skeleton

Use **Documentation ▶ Create HTML documentation** to create HTML documentation for the active submodel.

**Note:**

- The name of the file is inherited from the submodel with an *html* extension.
- This *.html* file is put in the *doc* directory of the **AMESim** node in which the submodel is stored.
- The *.html* file is constructed from the specification (*.spe*) and source code (*.c* and *.f*) of the submodel. Fill in the full description part of the source code as this forms a major part of the documentation.

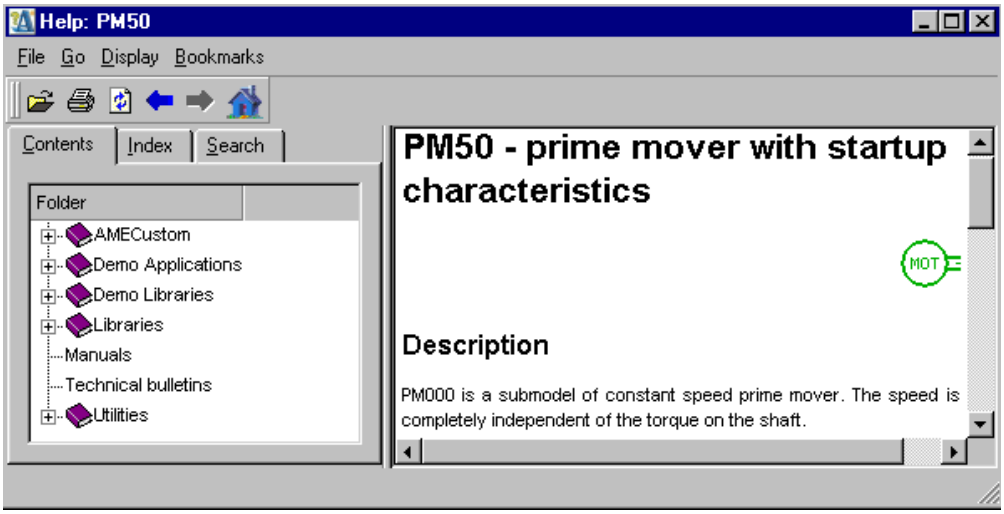
### Edit HTML documentation

Use **Documentation ▶ Edit HTML documentation** to modify the *Sketches and Equations* section of your submodel documentation. If no *HTML* editor is specified in the **AMESet** preferences (see section "AMESet preferences", page 146), you will be asked to select one.

### View HTML documentation

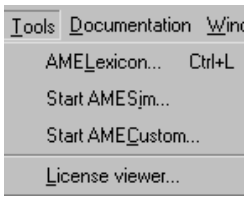
Use **Documentation ▶ View HTML documentation** to view the documentation generated for the active submodel. In contrast if you use **Help ▶ OnLine,** you get documentation on all submodels.

**Figure 5.8: Viewing HTML Submodel Documentation.**




## 5.4.8 Tools menu

The function of the second and third items is obvious.

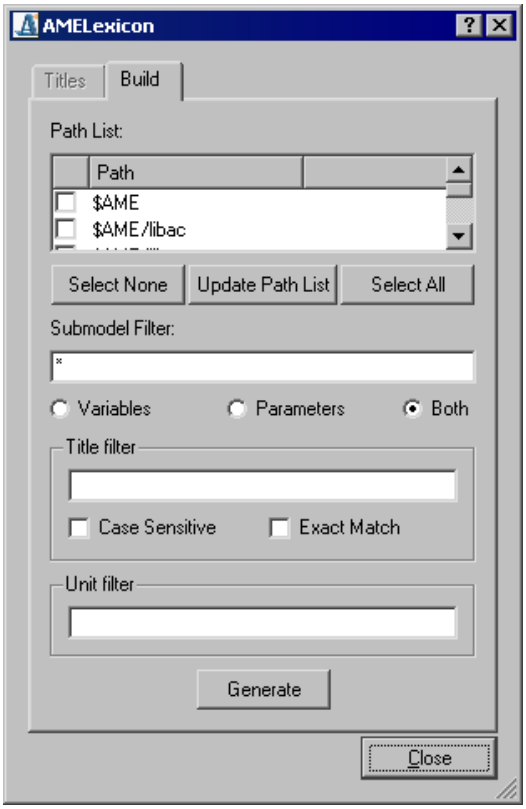



### AMELexicon

Use this facility to help you make submodels with consistent titles and units for *Parameters* and *Variables*.

When you use **Tools ▶ AMELexicon** the starting point is the *AMELexicon* dialog box.

**Figure 5.9: The AMELexicon dialog box under the Build tab.**




Note there are two tabs:

*Titles*

*Build*

*Titles* is for showing the results of an *AMELexicon* analysis. *Build* is for defining an analysis. Initially there is no completed analysis and hence the *Titles* tab is insensitive.

### The Build Tab for AMELexicon

The analysis to be performed is defined under the *Build* tab. To define an analysis follow these steps:

**Step 1: Set the path list.**

A list of directories or folders of **AMESim** nodes is displayed each with a check box. This is based on your current path list. The task is to check the boxes of the nodes you are interested in. The analysis will only be applied to the **AMESim** nodes that are checked.

The function of the *Select None* and *Select All* buttons is obvious. If you do not like the current path list, use **Options ▶ Path list...** to adjust it and then click on *Update Path List*.

### Step 2: Set the filters.

There are three: *Submodel Filter*, *Title filter*, *Unit filter*.

**Submodel Filter.** This specifies the submodels you want the analysis to apply to. The wild cards '*' (any string including null) and '?' (any character) may be used.

A further refinement is to specify whether you want the analysis to apply only to *Variables*, only to *Parameters* or to *Both*.

**Title filter**. This enables you to specify key words and complete sub-strings to search for in Parameters/Variables.

You can make the specification more precise using the *Case Sensitive* and *Exact Match* check buttons. If *Exact Match* is selected, the string must be a sub-string of a title otherwise the component words of the specified string are key words.

**Unit filter**. This enables you to limit the analysis to *Parameters*/*Variables* having a specified unit.

**Note** that you can have very restrictive filters and very general filters and both are useful.

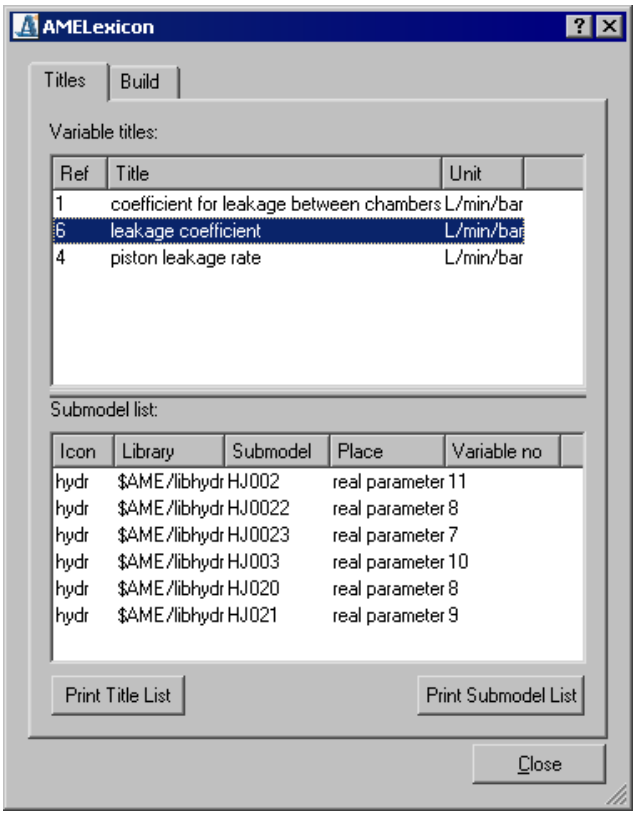
- If you select a single library with all parameters but no *Title* or *Unit* filters, you will have all the parameters (real, integer and text) in that library. You can then scroll through the lists looking for inconsistencies.
- If you are certain there are inconsistencies associated with a particular title, put a very restrictive *Title* filter to generate a short list. It is then easy the make the titles consistent.
- If you want to make your titles consistent with ones in an **AMESim** library, use the method described in "Using AMELexicon to set parameters", page 92 to Copy-Paste the **AMESim** title onto your submodel.

### Step 3: Click on *Generate*.

The analysis is performed, the results are displayed under the *Titles* tab (see Figure 5.10).

### The Titles Tab for AMELexicon

**Figure 5.10: The AMELexicon dialog box under the Titles tab.**



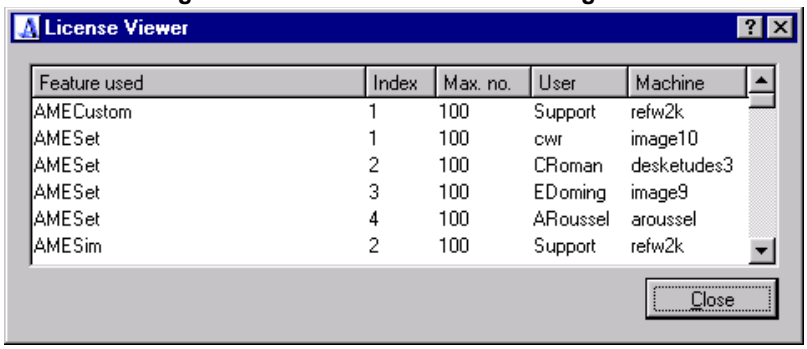

Under the *Titles* tab the results of an *AMELexicon* analysis are displayed. By selecting a particular title the *Submodel list* is reconstructed to show the ones that contain this title.

If you double click on a submodel in *Submodel list* it will be loaded into **AMESet**. This gives a easy way to Copy/Paste variable or parameter between submodels.

### License viewer

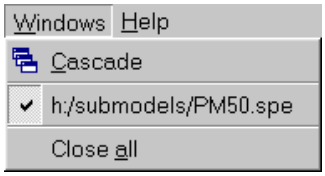
Select this item to see who is currently using **AMESim** product licenses. Normally this is only useful for clients who have multiple licenses. Note that you do not use a license for an **AMESim** library to use this library in **AMESet**. For example you can use a pneumatic library icon and make a copy of a pneumatic library submodel without using a pneumatic library license token.

**Figure 5.11: The License Viewer dialog box.**




| Feature used | Index | Max. no. | User | Machine |
|---|---|---|---|---|
| AMECustom | 1 | 100 | Support | refw2k |
| AMESet | 1 | 100 | cwr | image10 |
| AMESet | 2 | 100 | CRoman | desketudes3 |
| AMESet | 3 | 100 | EDoming | image9 |
| AMESet | 4 | 100 | ARoussel | aroussel |
| AMESim | 2 | 100 | Support | refw2k |

## 5.4.9 Windows menu




This comprises permanent items:

- Cascade.
- Close all.

An extra item is added for each open submodel specification. You can bring an open submodel specification to the top, i.e. make it the **active submodel**, by selecting it.

### Cascade

**Windows ▶ Cascade** arranges the windows corresponding to each open submodel so that each is visible but they overlap.

### Close all

**Windows ▶ Close all** initiates the process of closing all the open submodel specification. If there are unsaved changes, you will be asked if you want to save them.

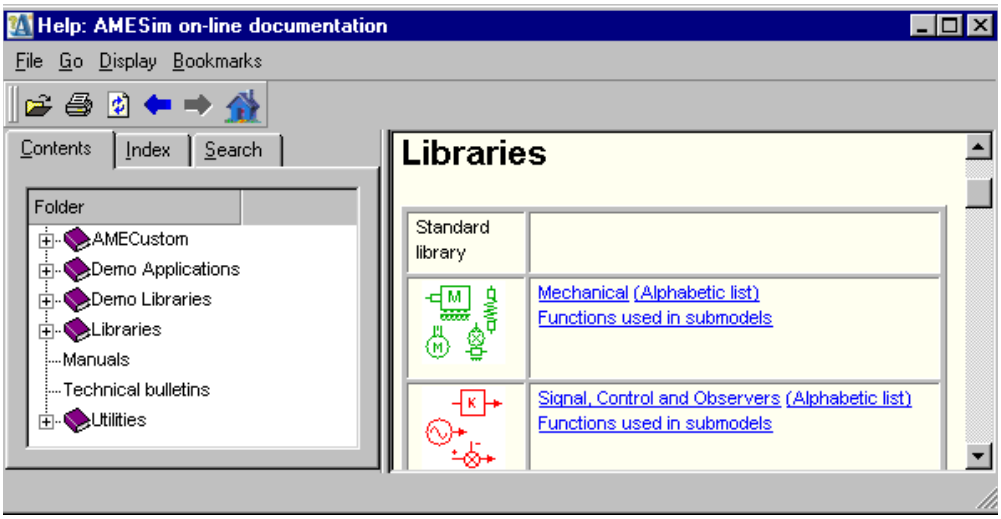
## 5.4.10 Help menu

### OnLine

Use **Help ▶ OnLine** to view documentation of **AMESim** submodels. These may be in libraries supplied as an **AMESim** product, submodels produced by you or by a colleague. Referring to Figure 5.3 on the left side of the screen you can find three tabs:

- *Contents*, which shows the list of the documentation topics.
- *Index*, from which you can type in a keyword and get the related entries.
- *Search*, from which you can get the list of all the documents containing at least one occurrence of a given keyword.

**Figure 5.12: On-line Help.**




You can also get information on **AMESim** utility functions that you can use in your submodels. As an example, if you wish to use the utility **dlimit,** you can get a description of it as in Figure 5.13.

**Figure 5.13: On-line help for dlimit.**

## Utility name: dlimit

## Purpose

Limits an input signal to a specified range.

## Description

This utility is a double/double precision function used to limit an input signal to a value within a specified range. function handles transition between limited and unlimited states as a discontinuity.

## Fortran 77 call prototype

```
double precision dlimit

external dlimit

double precision sig, lower, upper

integer reg
```

If you are writing a lot of **AMESim** submodels, you can probably save yourself a lot of time in the long term by browsing through these utilities. (See Figure 5.14)

**Figure 5.14: Selecting utilities for on-line documentation.**

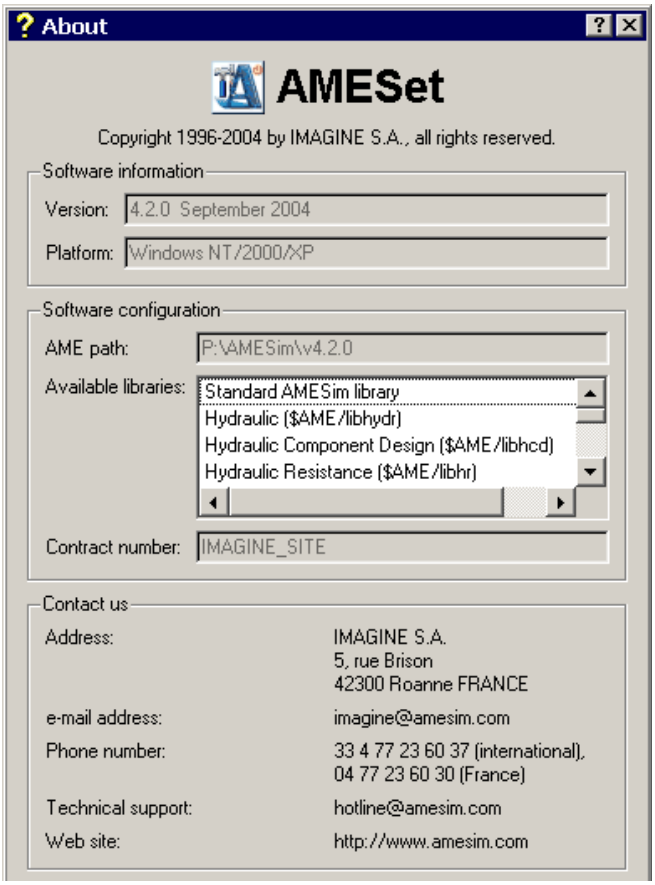
## Utilities for AMESim Submodels

When you write a number of **AMESim** submodels, you will find that certain physical phenomena occur repeatedly. This gives rise to a need to implement calculations for these phenomena. It would certainly be very inefficient to have to recode every time they were used and hence **AMESim** provides a library of utilities that you can call from your submodels. On this page the most important are breifly described, for a full list in alphabetic order, please go here. Here are some important examples with the names of the corresponding utilities:

| | |
|---|---|
| exit from the simulation from a submodel written in C | AmeExit |
| exit from the simulation from a submodel written in Fortran | famexit |
| stick-slip in linear motion | linert, linert1c, linert2c |
| stick-slip in rotary motion | rinert |
| physical limitations on the range of a variable | dlimit, dlimit1, llimit, ulimit, endst1b, endst2, checkvalue |
| pressure rate of change in a compressible fluid | pcdynm,pcdyn2 |

### About

**Figure 5.15: About AMESet**



This gives a lot of information on the version of **AMESet** you are using and the libraries to which you have access. If you make a telephone support call, you may need to create this dialog box to provide information requested by the support team.

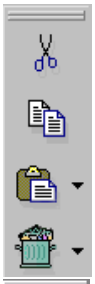
## 5.5 The AMESet toolbars

The toolbars consist of buttons all of which are equivalent to a menu item of the menu bar. In addition there is one pulldown menu.

**File ▶ New** or *Ctrl+N* (see page 135)

**File ▶ Open** or *Ctrl+O* (see page 136)

**File ▶ Save** or *Ctrl+S* (see page 136)



**Edit ▶ Cut** or *Ctrl+X* (see page 140)

**Edit ▶ Copy** or *Ctrl+C* (see page 141)

**Edit ▶ Paste** or *Ctrl+V* (see page 141)

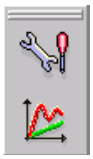
This is the *Trash Can* (see below).

Selection of the source code generated (C or F77).

**Code ▶ Generate code** (see page 157)

**Code ▶ Edit code** (see page 157)

**Code ▶ Compile code** (see page 157)



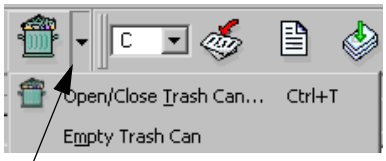
**Submodel ▶ Preview submodel parameters** (see page 155)

**Submodel ▶ Preview submodel variables** (see page 156)

### Use of the Trash Can

The *Trash Can* is a storage area were ports, variables and parameters which have been subjected to *Delete* are stored. (See Figure 5.22.)

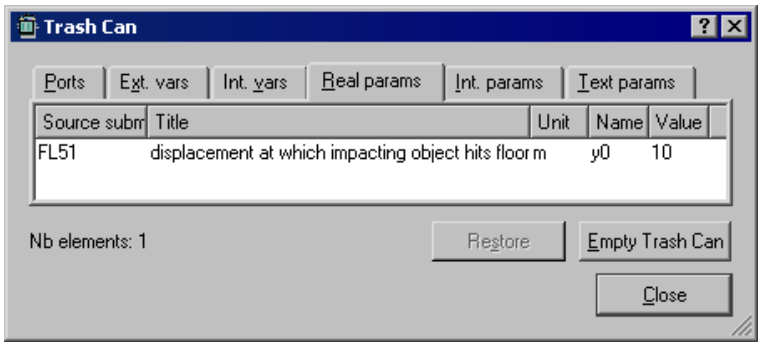
When you click to right of the *Trash Can* you get a menu of two items.




**Click here**

1. **Open/Close Trash Can..**. If the *Trash Can* dialog box is open, it will be closed else it will be opened as shown in Figure 5.16.

**Figure 5.16: The Trash Can dialog box.**




Note the 6 tabs for selecting ports, various variable types and various parameter types. You can select one or more items in the list and then:

- Drag and drop them onto a submodel.
- Click on the *Restore* button which will attempt to put them back from whence they came.

If you feel the *Trash Can* has too much in it, click on *Empty Trash Can*.

2. You can also select *Empty Trash Can* in the *Trash Can* menu to do the same thing.

## 5.6 The AMESet main window

This is the place where the submodel specifications are set. It is split up into two parts as shown in Figure 5.17. To the left are shown the **basic features** of the submodel which are:

- The icon associated with the submodel.
- A brief description.
- The number of ports with their types.
- The number of variables and parameters with their status.
- The number of stores.

- The submodel requirements.

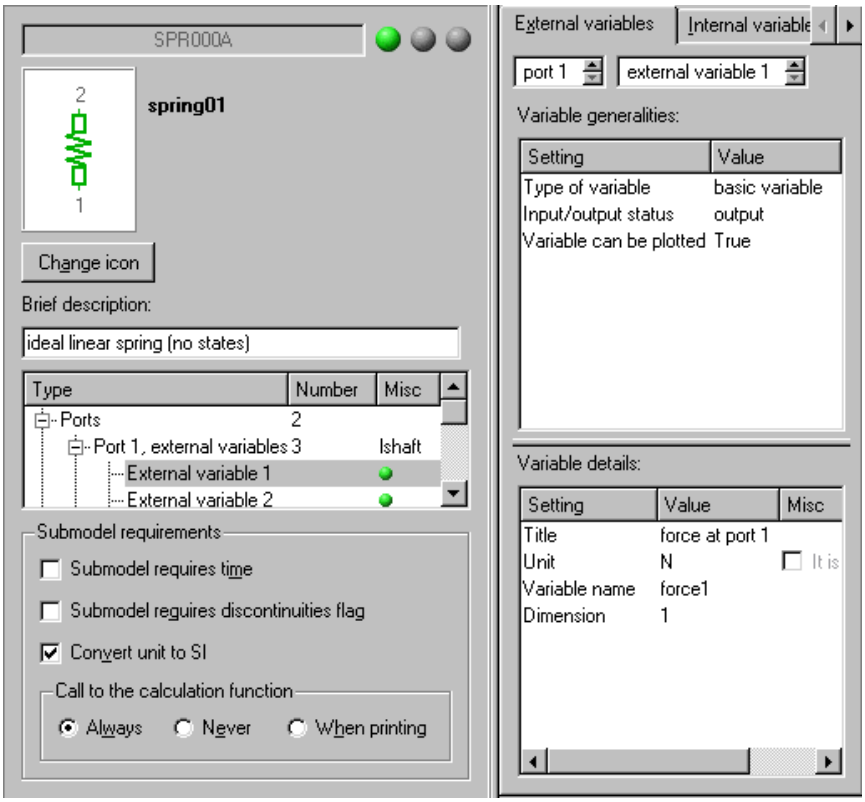
To the right are shown the **characteristics** of the selected variable or parameter which are, for the variables:

- The variable generalities: type of variable, plottability, input/output status.
- The variable details: title, unit, variable name, dimension...

and for the parameters:

- The parameter details: title, unit, variable name...

**Figure 5.17: The AMESet main window.**



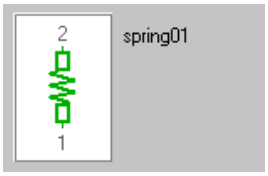

## 5.6.1 Setting the basic features of a submodel

### Setting / Changing the submodel icon

When you start creating a new submodel specification you can either

- select an icon in one of the available categories: this icon is then assigned to the submodel you are dealing with (as in Figure 5.18),

**Figure 5.18: All submodels must be associated with an icon.**




or

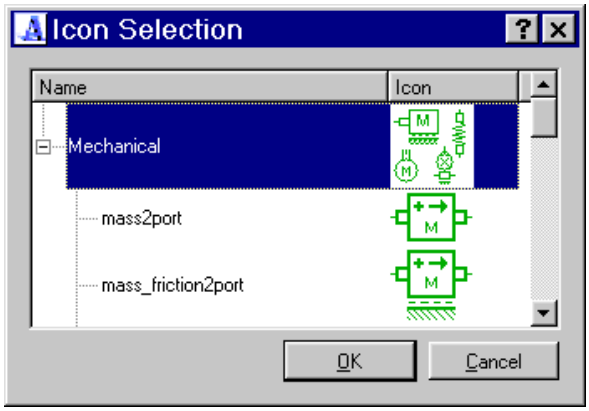
- you can use the menu **File ▶ New** (or **Ctrl+N**, or click on ) and no icon is assigned to your submodel for the time being (as shown in Figure 5.19).

**Figure 5.19: For New there is initially no icon.**

In both cases you can click on the button *Change icon* in order to replace the icon currently assigned to the submodel, or to assign an icon to the submodel which has no icon yet.

If you click on this button, the dialog box shown in Figure 5.20 appears. From there you get a list of the available categories and if you select one of these you will be able to choose an icon of the category you selected.

**Figure 5.20: Selecting an icon for a submodel.**

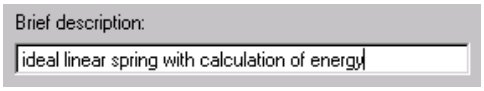



**An important point is that you only have access to the icons for which the number of ports and the port types are compatible with what you specified in the basic features (see "Declaring external variables", page 173).**

## Setting a brief description

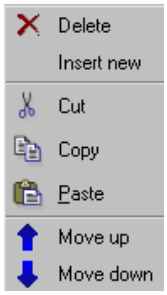
A field is at your disposal to type in a brief description for the submodel (see figure below). This field contains text, which will be displayed when the submodel will be selected in **AMESim**.

**Figure 5.21: Entering a brief description.**



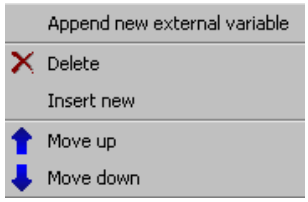

## Right click menus associated with ports, variables and parameters

If you select a variable or parameter and you click on the mouse right button, a menu similar to the one shown will appear.




If you select any port and you click on the mouse right button, a slightly different menu will appear.

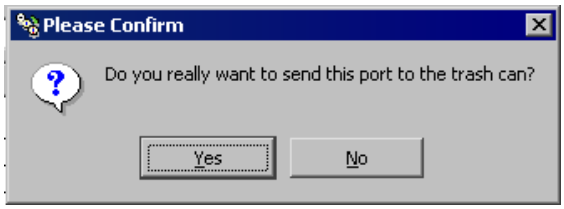
From there you can perform the actions on any port, variable or parameter:




The possible actions are now described:

- **Delete**: Select this menu item in order to remove the selected port, variable or parameter. You are asked to confirm. If you click on *Yes* the deleted object is put in the *Trash Can*.

**Figure 5.22: Confirming a delete.**




- **Insert new**: Select this menu item in order to insert a new port, variable or parameter

- **Cut**: Select this item in order to remove the selected variable or parameter. It is put into a buffer or clipboard and you can then use *Paste* to put it somewhere else. This does not apply to ports.
- **Copy**: Select this item in order to make a copy of the characteristics of the selected variable or parameter in the clipboard. You can then use *Paste* to put it somewhere else. This does not apply to ports.
- **Paste**: Select this menu item in order to assign to a variable or a parameter the same characteristics as in the clip board. This does not apply to ports.
- **Move up/down**: Use these menu items if you want to change the place of the selected port, variable or parameter. Note that for external variables, **AMESet** prevents you from breaking the following rules:
  - **Outputs must always be placed before Inputs.**
  - **Inputs must always be placed before Inputs with default.**
- **Append new external variable**: This only applies to ports. A new external variable is added at the end of the existing ones.

## Ports

Remember ports are used to connect components together. They are vitally important in **AMESim**. It is necessary to be able add, remove, move and set port types.

## Inserting a port

**There are three important points to consider.**

- **If you have an icon for the submodel, this sets the number of ports.**
- **If there is no icon, then the number of ports can easily be changed.**
- **If there is an icon, you can still insert extra ports but the submodel will lose it association with the icon.**

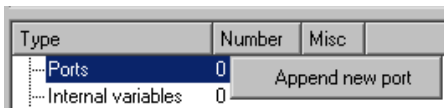
### Inserting a port when there are no ports

Do as follows:

1. Right-click on the *Port* item in the *Type* list.

   A menu appears.
2. Select *Append new port*.

   A new port is added. You now have to define its external variables.




### Inserting a port when there are one or more ports already

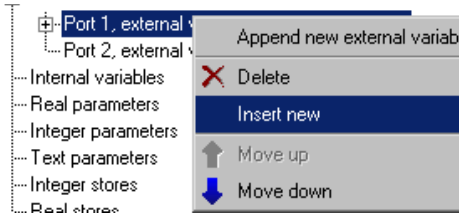
You can do as explained before. The port will go at the end of the existing ones.

You can move it to a different position. See "Moving a port", page 173.

You can also:

1. Right-click on one port in the *Type* list. A menu appears.
2. Select *Insert new*.

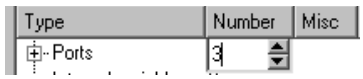
   A new port is added under the port you selected. You now have to define its external variables.




## Editing the number of ports

This is way of adding or removing ports.:

1. Next to the *Ports* entry in the *Type* column edit the value in the *Number* column. Enter the number directly or use the arrows in the 'spin box'.

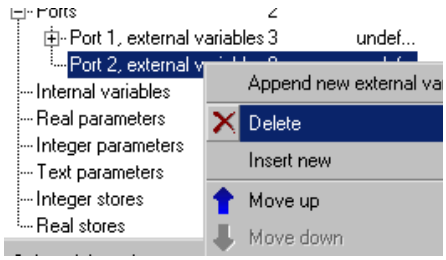



If you increase the number, ports are added at the end. If you decrease the number, ports are deleted from the end. If you increase the number of ports and then increase them back to the original number, you will find they are all there in undamaged condition!

## Removing a port

**To remove a port:**

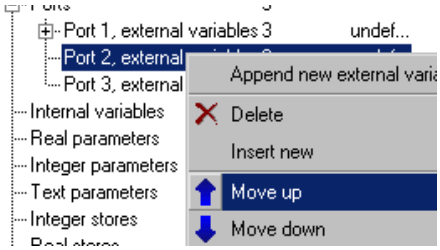
1. Right-click on the port you want to remove of the *Type* list.
2. Select *Delete*. You are asked to confirm. Deleted ports are put in the *Trash Can*.



## Moving a port

**To move a port up or down:**

1. Right-click on the port you want to move. A menu appears.
2. Use the items *Move up* and *Move down*.




Note that is the submodel has already been associated with an icon, the move may make the submodel incompatible with the icon. In this case **AMESet** will remove the association.

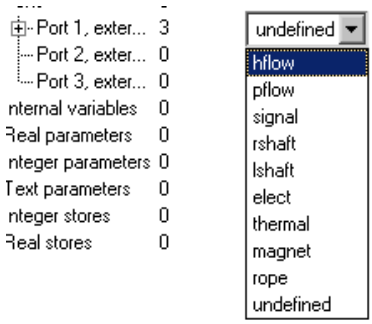
## Setting port types

If you find under the *Misc* column of an item corresponding to a port the key word *undefined*, you must change this to a standard port type. The simplest way to do this is to select an icon for the submodel. The ports will inherit the port type from the icon.

You can always edit the port type. Do this as follows:

Right click on the entry in the *Misc* column and select the type of port you want.

Remember **AMESet** will not allow you to save until the port type is defined.

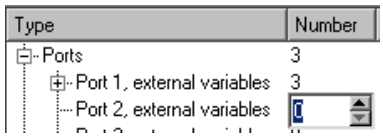



## Declaring external variables

These variables are associated with the ports of the submodel. If there are no ports, there can be no external variables. Set up the ports before you declare external variables. See “Ports”, page 171.

To declare external variables on a port:

1. Select the port.
2. Edit the *Numbers* field directly or using the ‘spin box’ arrows.



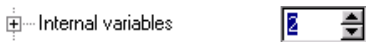
After this you must define further their characteristics. See "Setting the characteristics of an external variable", page 176.

## Declaring internal variables

These variables are available for plotting but they are not associated with any ports and they are neither inputs nor outputs.

To declare internal variables:

1. Select *Internal variables*.
2. Edit the *Numbers* field directly or using the 'spin box' arrows.

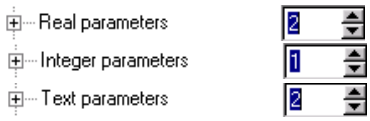



After this you must define further their characteristics. See "Setting the characteristics of an internal variable", page 178.

## Declaring real / integer / text parameters

These parameters are used to define the size or characteristics of the submodel. They can be real quantities, integer quantities or text expressions. To declare parameters:

1. Select *Real parameters*, *Integer parameters* or *Text parameters*.
2. Edit the *Numbers* field directly or using the 'spin box' arrows.




After this you must define further their characteristics. See "Setting the characteristics of a real parameter", page 180, "Setting the characteristics of an integer parameter", page 181 and "Setting the characteristics of a text parameter", page 184.

## Declaring integer / real stores

Stores are arrays that are accessible in both the initialization, calculation routines and from multi-line macros. Their main feature is they retain their values between calls. To declared stores:

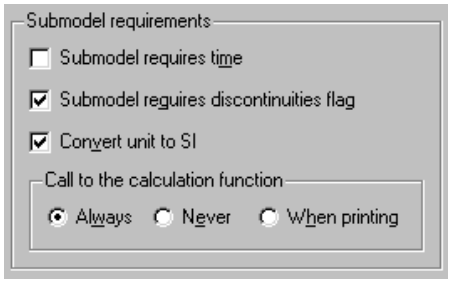
1. Select *Real stores* or *Integer stores*.
2. Edit the *Numbers* field directly or using the 'spin box' arrows.

Note that there must be an integer store for each activity variable. When you introduce an activity variable, **AMESim** increments the number of integer stores. When you remove an activity variable, **AMESim** decrements the number of integer stores.

**If there are *N* activity variables, the last *N* integer stores are reserved for these variables. Do not try to use them for any other purpose.**

### Setting the submodel requirements

**Figure 5.23: Submodel requirements.**




You can indicate your submodel requires time, discontinuity flag or unit conversions by putting a tick mark in the corresponding check box.

You can change the way the submodel calculation function will be called by **AMESim**:

- *Always* is the default setting and is convenient in most cases.
- If the calculation function is empty, you should click on the *Never* button. This will result in shorter simulation times when this submodel is used, since its calculation function will not called by **AMESim**.
- If you select *When printing*, the calculation function is only called when new data is added by **AMESim** in the simulation result file.

## 5.6.2 Setting the characteristics of variables and parameters

After declaring a variable or a parameter you must set its characteristics from the right part of the **AMESet** main window. If you select a variable or a parameter you have just declared, you will find that default characteristics are assigned to it. Information is given on the current selected variable or parameter number as shown below:

Note that there is a single traffic light next to each variable or parameter in the *Misc* column. It necessary expand items in the list to show individual parameters or variable. This works like the facility for the lights for the complete submodel (see “The traffic lights”, page 137). If it is orange or red you can get further information by expanding the *Misc* column or putting you pointer in the *Misc* column.

**Figure 5.24: Determining the cause of an error.**

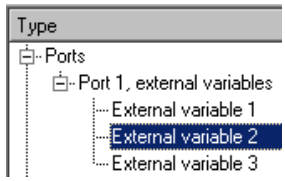
## Setting the characteristics of an external variable

There are two ways to select an external variable:

1. In the left part of the main menu expand the tree structure in the *Type* column until you see the external variable you want.
2. Click on it

   or

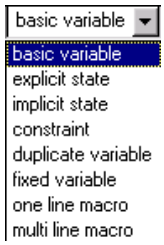
3. In the right part of the main window click on the *External variables* tab.
4. Adjust the port number and variable number by using the arrows on the 'spin boxes'.



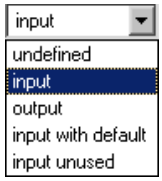
In order to define an external variable, the following information must be given:

**Variable generalities:**

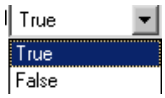
1. **Type of variable**: It is chosen in a list you get by clicking in the column labeled *Value*. The default type is *basic variable*.




2. **Input / output status**: This characteristics is only available for external variables the type of which is *basic variable.* It is chosen from a list you get by clicking in the column labeled *Value*. The default status is *undefined* but you must change it to something else before you can save the submodel.




3. **Variable can be plotted**: This characteristics is only available for external variables of type *basic variable*, *fixed variable*, *one line macro* or *multi line macro.* It is chosen in a list you get by clicking in the column labeled *Value*. It is either *True* or *False*. The default state is *True*.



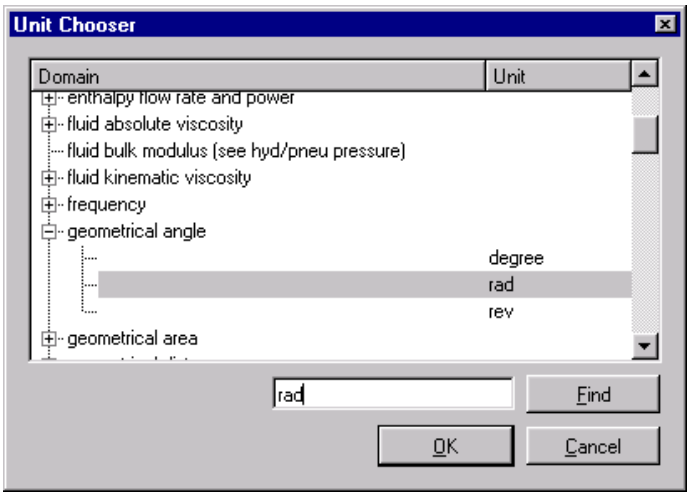

4. **Duplicate type**: This characteristics is only available for external variables the type of which is *duplicate variable.* It is chosen in a list you get by clicking in the column labeled *Value*. It is either *simple* or *reversed sign*. The default type is *simple*.

**Variable details:**

1. **Title**: This characteristics is common for all the types of external variables except for the type *duplicate variable*. Click on the column *Value* and type in a title for the external variable. This title will appear in **AMESim** when you will use the submodel.

2. **Unit**: This characteristics is common for all the types of external variables except for the type *duplicate variable*. Click on the column *Value* and type in the unit of the external variable. Alternatively you can click on the button ... in the column, and you will get a dialog box for selecting the unit:

**Figure 5.25: The Unit Chooser**




3. **It is a difference**: This is a boolean field which becomes available only when the external variable has a unit set to either a pressure (bar, Pa, barA...) or a temperature (degC, degF, ...). Set this field to *True* when the variable is either a pressure drop or a temperature difference. Leave it to *False*, its default value, otherwise. This characteristics is used in **AMESim** when preferred units are required so that absolute units are replaced by relative ones (or the opposite). **If the variable is a difference and an offset is needed for the unit conversion, then this offset will be ignored.**

4. **Variable name**: This characteristics is common for all the types of external variables except for the type *duplicate variable*. Click on the column *Value* and type in a name for the external variable. This name will be used in the submodel code.

5. **Dimension**: This characteristics is common for all the types of external variables except for the types *duplicate variable* and *one line macro*. Click on the column *Value* and type in a dimension for the external variable.

6. **Minimum expected value**, **Default value** and **Maximum expected value**: These characteristics are available for external variables the type of which is *explicit state*, *implicit state*, *constraint or fixed variable.* They are assigned by clicking on the column *Value*. If the three values are identical, the external

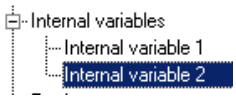
variable will not appear in **AMESim** and it will not be possible to change its value.

7. **Variable derivative name**: This characteristics is only available for external variables the type of which is *explicit state.* Click on the column *Value* and type in a name for the derivative of the external variable. This name will be used in the submodel code.
8. **Variable residual name**: This characteristics is only available for external variables the type of which is *implicit state* or *constraint.* Click on the column *Value* and type in a name for the residual associated with the external variable. This name will be used in the submodel code.
9. **Residual unit**: This characteristics is only available for external variables the type of which is *implicit state* or *constraint.* Click on the column *Value* and type in the unit of the residual associated with the external variable. Alternatively you can click on the button ... in the column, and you will get a dialog box for selecting the unit as in Figure 5.25.

## Setting the characteristics of an internal variable

There are two ways to select an internal variable:

1. In the left part of the main menu expand the tree structure in the *Type* column until you see the internal variable you want.




2. Click on it

or

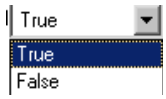
3. In the right part of the main window click on the *Internal variables* tab.
4. Adjust the *internal variable* number by using the arrows on the 'spin box'.

In order to define an internal variable, the following information must be given:

### Internal variable generalities:

1. **Type of variable**: It is chosen in a list you get by clicking in the column labeled *Value*. The default type is *basic variable*.

2. **Variable can be plotted**: This characteristics is only available for internal variables of type *basic variable*, *fixed variable* or *multi line macro*. It is chosen in a list you get by clicking in the column labeled *Value*. It is either *True* or *False*. The default state is *True*.




**Internal variable details:**

1. **Title**: Click on the column *Value* and type in a title for the internal variable. This title will appear in **AMESim** when you will use the submodel.
2. **Unit**: Click on the column *Value* and type in the unit of the internal variable.

   Alternatively you can click on the button ... in the column, and you will get a dialog box for selecting the unit as in Figure 5.25.
3. **It is a difference**: This is a boolean field which becomes available only when the internal variable has a unit set to either a pressure (bar, Pa, barA...) or a temperature (degC, degF, ...). Set this field to *True* when the variable is either a pressure drop or a temperature difference. Leave it to *False*, its default value, otherwise. This characteristics is used in **AMESim** when preferred units are required so that absolute units are replaced by relative ones (or the opposite). **If the variable is a difference and an offset is needed for the unit conversion, then this offset will be ignored.**
4. **Variable name**: Click on the column *Value* and type in a name for the internal variable. This name will be used in the submodel code.
5. **Dimension**: Click on the column *Value* and type in a dimension for the internal variable.
6. **Minimum expected value**, **Default value** and **Maximum expected value**: These characteristics are available for internal variables the type of which is *explicit state*, *implicit state*, *constraint or fixed variable.* They are assigned by clicking on the column *Value*. If the three values are identical, the internal variable will not appear in **AMESim** and it will not be possible to change its value.
7. **Variable derivative name**: This characteristics is only available for internal variables the type of which is *explicit state.* Click on the column *Value* and type in a name for the derivative of the internal variable. This name will be used in the submodel code.
8. **Variable residual name**: This characteristics is only available for internal variables the type of which is *implicit state* or *constraint.* Click on the column *Value* and type in a name for the residual associated with the internal variable. This name will be used in the submodel code.
9. **Residual unit**: This characteristics is only available for internal variables the type of which is *implicit state* or *constraint.* Click on the column *Value* and type in the unit of the residual associated with the internal variable. Alternatively

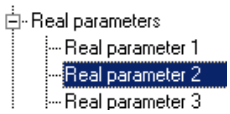
   you can click on the button ... in the column, and you will get a dialog box for selecting the unit as in Figure 5.25.

10. **Physical type**, **Physical domain**, **Variable name suffix**: These characteristics are only available for *activity* variables. The **Physical type** is selected from a list, it can be set to *R*, *C* or *I*. The **Physical domain** is also selected from a list, it can be set to *hydraulic*, *mechanical*, *electrical*, *thermal*, *magnetic* or *pneumatic*. The **Variable name suffix** must be typed in, it will be used by **AMESet** to generate the name of the power variable associated with the *activity* variable.

## Setting the characteristics of a real parameter

There are two ways to select an real parameter:

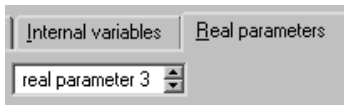
1. In the left part of the main menu expand the tree structure in the *Type* column until you see the real parameter you want.




2. Click on it

   or

3. In the right part of the main window click on the *Real parameter* tab.




4. Adjust the *real parameter* number by using the arrows on the ‘spin box’.

### Real parameter details

In order to define a real parameter, the following information must be given:

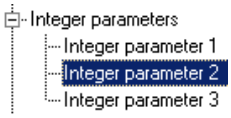
1. **Title**: Click on the column *Value* and type in a title for the real parameter. This title will appear in **AMESim** when you will use the submodel.
2. **Unit**: Click on the column *Value* and type in the unit of the real parameter.

   Alternatively you can click on the button ... in the column, and you will get a dialog box for selecting the unit as in Figure 5.25.
3. **It is a difference**: This is a boolean field which becomes available only when the real parameter has a unit set to either a pressure (bar, Pa, barA...) or a temperature (degC, degF, ...). Set this field to *True* when the parameter is either a pressure drop or a temperature difference. Leave it to *False*, its default value, otherwise. This characteristics is used in **AMESim** when preferred units are required so that absolute units are replaced by relative ones (or the opposite). **If the parameter is a difference and an offset is needed for the unit conversion, then this offset will be ignored.**
4. **Variable name**: Click on the column *Value* and type in a name for the real parameter. This name will be used in the submodel code.
5. **Minimum expected fixed value**, **Default fixed value** and **Maximum expected fixed value**: These characteristics are assigned by clicking on the column *Value*. If the three values are identical, the real parameter will not appear in **AMESim** and it will not be possible to change its value.

## Setting the characteristics of an integer parameter

There are two ways to select an integer parameter:

1. In the left part of the main menu expand the tree structure in the *Type* column until you see the integer parameter you want.




2. Click on it

or

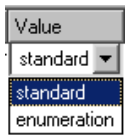
3. In the right part of the main window click on the *Integer parameter* tab.

4. Adjust the *integer parameter* number by using the arrows on the 'spin box'.

### Integer parameter generalities

There are two types of integer parameter: *standard* and *enumeration*.

Set the integer parameter type.




### Integer parameter details

Regardless of the integer parameter type, the following information must be given:

1. **Title**: Click on the column *Value* and type in a title for the integer parameter. This title will appear in **AMESim** when you will use the submodel.
2. **Variable name**: Click on the column *Value* and type in a name for the integer parameter. This name will be used in the submodel code.

The remaining information to be provided depends on the integer parameter type.

### Parameter details for standard integer parameters

**Minimum expected fixed value**, **Default fixed value** and **Maximum expected fixed value**: These characteristics are assigned by clicking on the column *Value*. If the three values are identical, the integer parameter will not appear in **AMESim** and it will not be possible to change its value.

### Parameter details for enumeration integer parameters

**Note** The enumeration facility is extremely powerful. It require great care to set it up well but the result is a submodel that is very easy to use. When you use enumeration, make frequent use of *Parameter Preview* to be sure you are really getting what you intended.

There are two fields to set.

1. **Configure enumeration**. To set or edit this click on the ... button in the *Value* field. The *Configure Enumeration* dialog box appears.

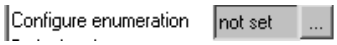
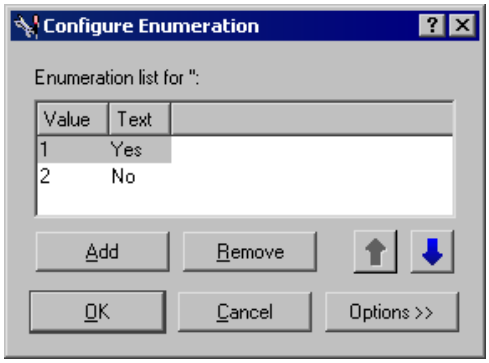
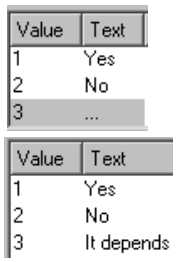



**Figure 5.26: The Configure Enumeration dialog box.**




There is a list of text strings which can be set to anything reasonably. Embedded blanks are allowed. Four buttons allow you to edit the list.

**Add**. Click on this button to add a list item. It is added at the bottom. Fill the text string. Embedded blanks are allowed.



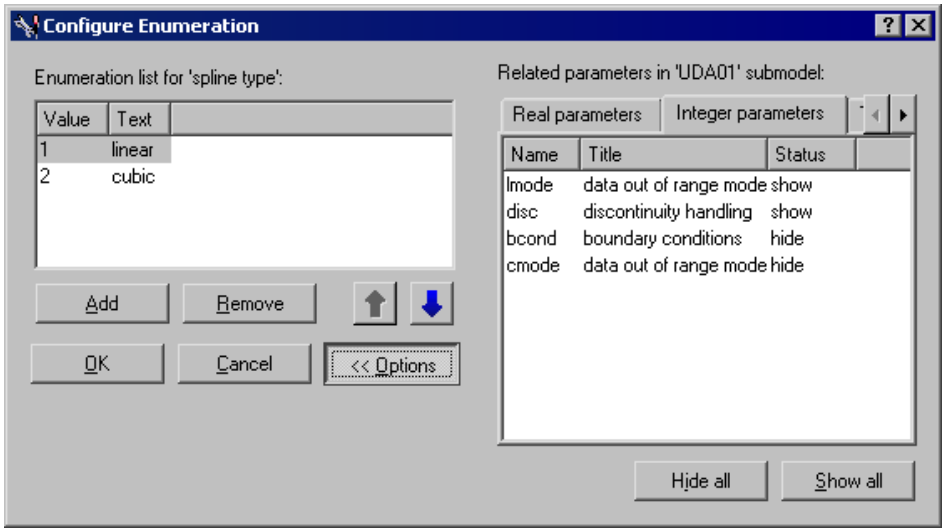

**Remove**. Select an item in the list and click on an this button to remove it.

Select an item in the list and click on this button to move it one place up the list.

Select an item in the list and click on this button to move it one place down the list.

If you select an item in the enumeration list and then click on the *Options* button, you get an expanded dialog box. This is used to selectively hide or show real parameters, text parameters and other integer parameters when this enumeration value is set. The following figure show the submodel UDA01 associated with the icon .

**Figure 5.27: The expanded Configure Enumeration dialog box.**




Note the three tabs:

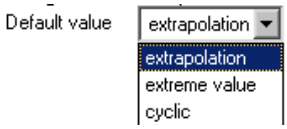
*Real Parameters*

*Integer parameters*

*Text parameters*

Note also the *Hide all* and *Show all* buttons. Individual hide/show values are set using a menu under *Status*.

2. The *Default value* field by default is set to the first enumeration string. It can be changed using the menu available n the *Value* column.



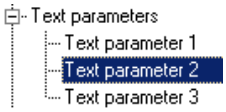

Note that there are some restriction on enumeration integer parameters hiding parameters:

- An enumeration integer parameter cannot hide itself!
- If an enumeration parameter can be hidden by another enumeration parameter, it cannot hide any parameters. The *Options* button will be insensitive.

## Setting the characteristics of a text parameter

There are two ways to select an text parameter:

1. In the left part of the main menu expand the tree structure in the *Type* column until you see the text parameter you want.




2. Click on it

   or

3. In the right part of the main window click on the *Text parameter* tab.

4. Adjust the *text parameter* number by using the arrows on the 'spin box'.

In order to define a text parameter, the following information must be given.

### Text parameter generalities

**Text type**: It is chosen in a list you get by clicking in the column labeled *Value*. The default type is *undefined*.

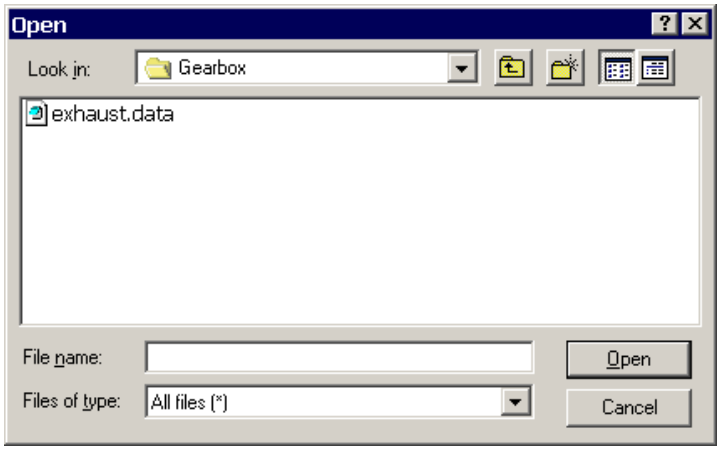
- Use *input file* if the text parameter specifies a data file that must be **read** when the simulation run.
- Use *expression* if it is a mathematical expression in term of some token(s) (e.g. *x*) that must be evaluated when the simulation runs.
- Use *undefined* for all other cases.

### Parameter details:

1. **Title**: Click on the column *Value* and type in a title for the text parameter. This title will appear in **AMESim** when you will use the submodel.
2. **Default value**: Click on the column *Value* and type in the text you want to assign.

   If the *Text type* is *input file*, you can use the button ... to browse the default file instead of typing its name and path:

**Figure 5.28: Browsing for a data file.**




If the *Text type* is set to *expression* type an expression in terms of the specified tokens. The expression will be checked for validity.

3. If the type is expression:

   **Tokens**: Click on the column *Value* and type in the token(s) that will be allowed in the expression of the parameter. If more than one token are declared, these must be separated by comas or blank spaces.

## 5.7 Debugging AMESim submodels

No matter how carefully you construct submodels, you will eventually find yourself in the situation of having a submodel that does not work. Finding out why it does not work can be a time consuming and difficult task. The main techniques in debugging the submodel are:

- examining the submodel source code,
- inserting print statements in the submodel code,
- running the complete simulation in a source code debugger.

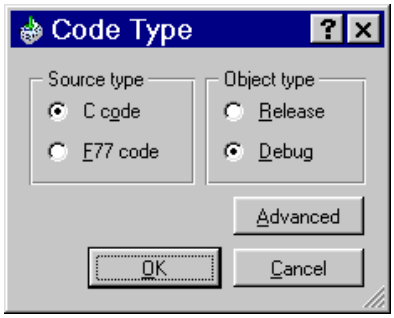
Much can be achieved with the first two techniques provided a systematic approach is used. However, if you have access to a source code debugger, it is well worth learning how to use it. It is not appropriate to give a tutorial on any particular debugger in this manual but it is necessary to point out a few special aspects of running an **AMESim** executable in a debugger.

The easiest way is to follow the procedure below:

1. Compile your submodel in debug mode (as opposed to release mode) in order to get a special object file for your submodel:

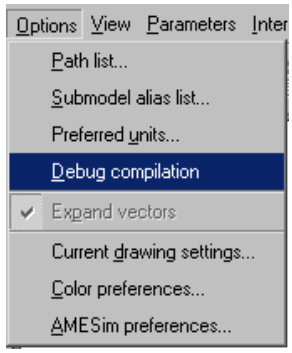
   - Select the **AMESet Code ▶ Code type** menu item, the dialog box shown below will appear:

**Figure 5.29: Selecting the debug option.**




- Click on the button *Debug* in the *Object type* group box and click on *OK*.
- Compile your submodel by clicking on the button or by selecting he **Code ▶ Compile code** menu item.

2. In **AMESim**, operate the *Options* menu. If it is not ticked already, select *Debug compilation*.




3. Create a very simple model in AMESim that uses your submodel and save it: this will produce a C file associated with this model. Note that if you save your model as *NAME.ame*, then the C file will be called *NAME_.c*.
4. Do a quick run in AMESim to ensure all the data files are written.
5. Start this executable from your debugger.

## 5.8 Summary of variable assignments

The following two tables summarize how variables are assigned or checked in the submodel initialization and calculation function or subroutine. To avoid use of '*'s the code is presented in F77.

| Type of variable | Example of code in initialization function/subroutine | Comment |
|---|---|---|
| Basic variable: that is an **input with default**. | Normally you do not write any code. | **AMESet** generates code to set these to their default value. You could change the values but not normally necessary. |
| Explicit state variable | `if(x .gt. xmax)then`<br>`  print*,'Illegal value of '`<br>`  print*,'displacement. Resetting to '`<br>`  print*,xmax`<br>`  x = xmax`<br>`  if(error .ne. 2)error = 1`<br>`endif` | Can check and reassign values of explicit states. |
| Implicit state variable | See above | Can check and reassign values of implicit states. |
| Constraint variable | Normally you do not write any code. | Can check and reassign values of constraint variables but this is not normally necessary. |
| Duplicate variable | No code. | There is no access to duplicate variables in the initialization function. |
| On-line macro variable | No code. | There is no access to one-line macro variables in the initialization function. |
| Multi-line macro variable | No code | There is no access to multi-line macro variables in the initialization function. |
| Fixed variable | `if(p .lt. -1.0d0)then`<br>`  print*,'Pressure value to low'`<br>`  print*,'Resetting to -1 bar'`<br>`  p = -1.0d0`<br>`  if(error .ne. 2)error = 1`<br>`endif` | Can check and reassign values of fixed variables. |

| Type of variable | Example of code in calculation function/subroutine | Comment |
|---|---|---|
| Basic variable which an output:<br>any internal,<br>any external output | `x = y + z` | Explicit assignment. |
| Explicit state variable | `vdot = force/mass` | Explicit assignment of derivative of explicit state. |
| | `if(flag .eq. 0)then`<br>`  if(x .gt. xmax)then`<br>`  x = xmax`<br>`  endif`<br>`endif` | The state variable may be reassigned only if *flag* = 0. |
| Implicit state variable | `C  vdot is the derivative on entry`<br>`C  Set acceleration`<br><br>`  accel = vdot` | Derivative and residual share the same name. On entry set to derivative. |
| | `C  vdot must be reassigned to`<br>`C  the residual`<br><br>`  vdot = mass*vdot - force` | On exit must be set to the residual. |
| | `if(flag .eq. 0)then`<br>`  if(x .gt. xmax)then`<br>`  x = xmax`<br>`  v = 0.0`<br>`  endif`<br>`endif` | The state variable may be assigned only if *flag* = 0. |
| Constraint variable | `vres = f1 -f2` | Explicit assignment of residual. |
| Duplicate variable | No code | There is no access to duplicate variables in the calculation function. |
| On-line macro variable | No code | There is no access to one-line macro variables in the calculation function. |
| Multi-line macro variable | No code here but in the multi-line macro variable function | |

| Type of variable | Example of code in calculation function/subroutine | Comment |
|---|---|---|
| Fixed variable | No code here | There is no access to fixed variables in the calculation function. |
| Activity variable | `powImass = mass * accel * v` | Explicit assignment of associated power variable. |

# 5.9 Useful shortcuts for AMESet

| Facility | Shortcut |
|---|---|
| Create a new submodel | **Ctrl+N** |
| Open a file | **Ctrl+O** |
| Save configuration | **Ctrl+S** |
| Quit | **Ctrl+Q** |
| Cut | **Ctrl+X** |
| Copy | **Ctrl+C** |
| Paste | **Ctrl+V** |
| Move up | **Ctrl+Up** |
| Move down | **Ctrl+Down** |
| Find | **Ctrl+F** |
| Generate code | **F5** |
| Edit code | **F6** |
| Compile code | **F7** |

# Appendix A: Creating your own Fluid Properties

## Introduction

Please note that this appendix is intended only for users having access to the Hydraulic library.

If you have access to the Hydraulic library, **AMESim** permits you to simulate systems containing more than one fluid. FP04 is a standard fluid properties submodel supplied in the **AMESim** Hydraulic Library.

If you have your own ideas on fluid properties, you have the opportunity to install your own properties. There are two template submodels which are stored in the tutorial/submodels directory of the **AMESim** system directory. FP50 and FP51, and the idea is to copy one or both of them to your local working area and use **AMESet** to insert your equations. This means the density, the bulk modulus and the viscosity of this fluid submodel will be calculated by your own functions.

In its original form FP50 is set up with one integer parameter:

*index of hydraulic fluid*

The idea is you write your own *rhoatp*, *bmatp* and *muatp* functions.

In this appendix an example of the use of FP50 is given.

## New Fluid Properties: mathematical model

We will assume we want to create a fluid with the following characteristics:

- Density varies with the current pressure according to the formula:

$$\rho = \rho 0(1 + a \times P + b \times P^2)$$ See **Ref. [1]**

where $\rho 0$ is the density at atmospheric pressure, a and b are two coefficients and $P$ is the current pressure in Pa.

- Bulk modulus is an iso-thermal value which is defined from the density as follows:

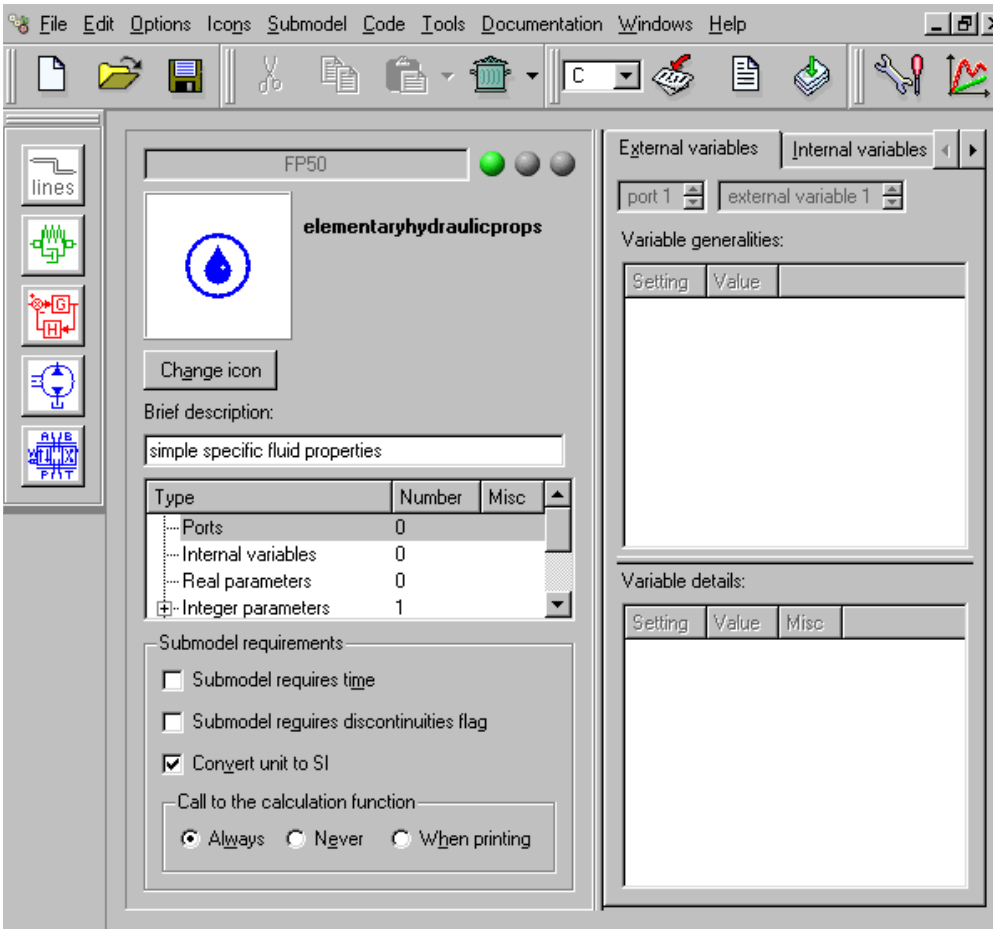
$$B = \frac{\rho}{d\rho / dP} = \frac{1 + P(a + b \times P)}{a + 2 \times b \times P}$$

- Absolute viscosity is assumed to be constant and equal to 5 cP.

## Creating the new FP50 submodel

Using this mathematical model you can now create the corresponding submodel. First start **AMESet** and use **File ▶ Open...** and browse for *FP50.spe* in the *tutorial/submodels* directory of the **AMESim** system directory. Start **AMESet** and then select the file FP50.spe from your working area. A display similar to that shown in Figure A. 1 should appear.

**Figure A. 1: AMESet with FP50 loaded.**




Note that an integer (the fluid index) is already defined, but you need three parameters ($\rho 0$ , $a$ and $b$). Declare them using the values as in Figure A. 2.

**Figure A. 2: Values of the parameters**

External variables | Internal variables | Real parameters

real parameter 1

Parameter details:

| Setting | Value |
|---|---|
| Title | density at atmospheric pressure |
| Unit | kg/m**3 |
| Variable name | density |
| Minimum expected value | 0 |
| Default value | 850 |
| Maximum expected value | 10000 |

External variables | Internal variables | Real parameters

real parameter 2

Parameter details:

| Setting | Value |
|---|---|
| Title | pressure coefficient |
| Unit | 1/Pa |
| Variable name | pcoeff |
| Minimum expected value | -1 |
| Default value | 6.35e-010 |
| Maximum expected value | 1 |

External variables | Internal variables | Real parameters

real parameter 3

Parameter details:

| Setting | Value |
|---|---|
| Title | pressure squared coefficient |
| Unit | 1/Pa/Pa |
| Variable name | p2coeff |
| Minimum expected value | -1 |
| Default value | -1.19e-018 |
| Maximum expected value | 1 |

Save your submodel, create the C code skeleton, and edit it. You must now update the DESCRIPTION section of the submodel, its PARAMETER SETTINGS section and fill in the private code part (the new text added is in bold):

```
/* >>>>>>>>>>>>Insert Private Code Here. */

/* Global variables associated with the submodel parameters */

static double gdensity;
static double gpcoeff;
```

```
static double gp2coeff;

#ifdef _NO_PROTO
static double rhoatp(tcelsius, p)
double *tcelsius;
double *p;
#else
static double rhoatp(double *tcelsius, double *p)
#endif
{
   double press;
   double rho;
   press = *p;
   rho   = gdensity*(1+press*(gpcoeff+gp2coeff*press));
   return rho;
}

#ifdef _NO_PROTO
static double bmatp(tcelsius, p)
double *tcelsius;
double *p;
#else
static double bmatp(double *tcelsius, double *p)
#endif
{
   double press;
   double bm;
   press = *p;
   bm    = 1+press*(gpcoeff+gp2coeff*press);
   bm   /= gpcoeff+2*gp2coeff*press;
   return bm;
}

#ifdef _NO_PROTO
static double muatp(tcelsius, p)
double *tcelsius;
double *p;
#else
static double muatp(double *tcelsius, double *p)
#endif
{
```

```
   return 0.005;
}
/* <<<<<<<<<<<<End of Private Code. */
```

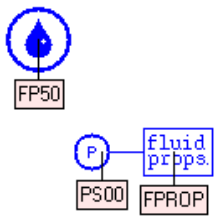
Finally add the following lines in the fp50in_ executable statements:

```
/* >>>>>>>>>>>>Initialization Function Executable Statements. */

  /* Global variables used in the local ...atp functions are set here
*/

   gpcoeff  = pcoeff;
   gp2coeff = p2coeff;
   gdensity = density;

   /* Install the fluid properties */
   fpuserd_( &fpi, rhoatp, bmatp, muatp );
   sethdind_(&fpi);

/* <<<<<<<<<<<<End of Initialization Executable Statements. */
```

Save your modification in a suitable **AMESim** node and compile the new submodel. You are now ready to use your new personal fluid submodel.

Start **AMESim** in your working directory and build the system below:

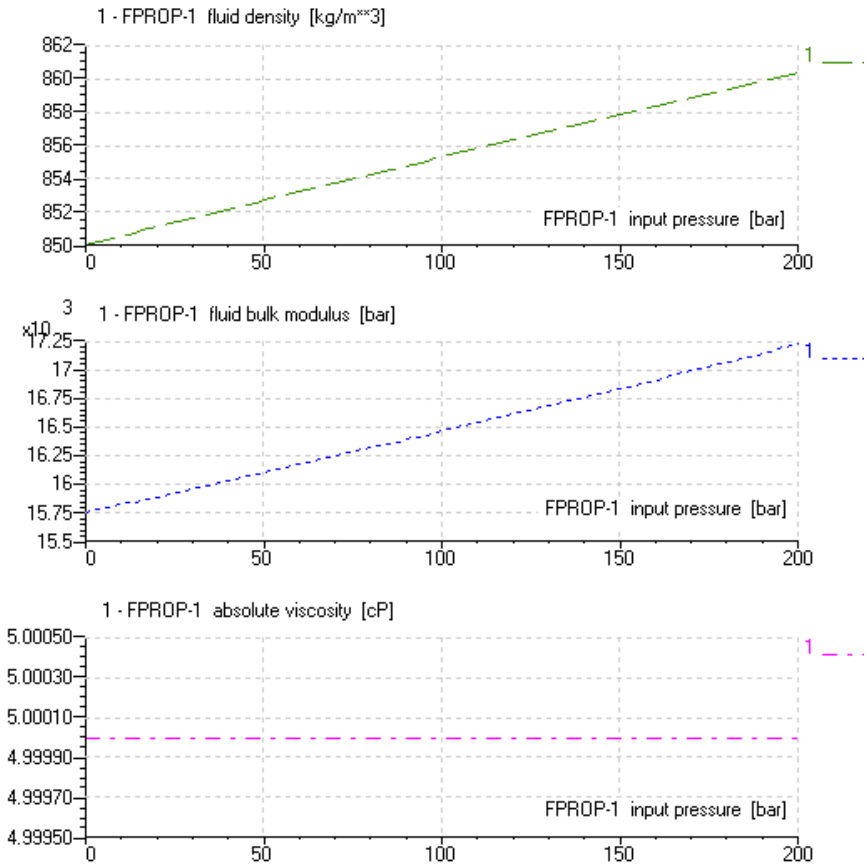
**Figure A. 3: Build this system**




Select the FPROP submodel for the *fluid props.* icon and set the parameter index of hydraulic fluid to 1. Change the parameters of the pressure input to get a ramp from 0 to 200 bar in 10 seconds.

Start a simulation and plot the density, the bulk modulus and the viscosity against the pressure:

**Figure A. 4: See the results**




You can now adjust the FP50 parameters in order to get closer to the characteristics of the fluid you want to simulate.

The submodel skeleton FP51 is similar but it is constructed to make it easier to use tables of values.

### References

[1]. Blackburn J.F., G. Reethof and J.L. Shearer, Fluid Power Control, 1960, New York: Technology Press of M.I.T. and Wiley.

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## Reporting Bugs and using the Hotline Service

**AMECustom** is a large piece of software containing many hundreds of thousands of lines of code. With software of this size it is inevitable that it contains some bugs. Naturally we hope you do not encounter any of these but if you use **AMECustom** extensively at some stage, sooner or later, you may find a problem.

Bugs may occur in the pre- and post-processing facilities of **AMESim**, **AMERun**, **AMESet**, **AMECustom** or in one of the interfaces with other software. Usually it is quite clear when you have encountered a bug of this type.

Bugs can also occur when running a simulation of a model. Unfortunately it is not possible to say that, for any model, it is always possible to run a simulation. The integrators used in **AMECustom** are robust but no integrator can claim to be perfectly reliable. From the view point of an integrator, models vary enormously in their difficulty. Usually when there is a problem it is because the equations being solved are badly conditioned. This means that the solution is ill-defined. It is possible to write down sets of equations that have no solution. In such circumstances it is not surprising that the integrator is unsuccessful. Other sets of equations have very clearly defined solutions. Between these extremes there is a whole spectrum of problems. Some of these will be the marginal problems for the integrator.

If computers were able to do exact arithmetic with real numbers, these marginal problems would not create any difficulties. Unfortunately computers do real arithmetic to a limited accuracy and hence there will be times when the integrator will be forced to give up. Simulation is a skill which has to be learnt slowly. An experienced person will be aware that certain situations can create difficulties. Thus very small hydraulic volumes and very small masses subject to large forces can cause problems. The *State count* facility can be useful in identifying the cause of a slow simulation. An eigenvalue analysis can also be useful.

The author remembers spending many hours trying to understand why a simulation failed. Eventually he discovered that he had mistyped a parameter. A hydraulic motor size had been entered making the unit about as big as an ocean liner! When this parameter was corrected, the simulation ran fine.

It follows that you must spend some time investigating why a simulation runs slowly or fails completely. However, it is possible that you have discovered a bug in an **AMESim** submodel or utility. If this is the case, we would like to know about it. By reporting problems you can help us make the product better.

On the next page is a form. When you wish to report a bug please photocopy this form and fill the copy. You telephone us, having the filled form in front of you means you have the information we need. Similarly include the information in an email.

To report the bug you have three options:

- reproduce the same information as an email
- telephone the details
- fax the form

Use the fax number, telephone number or email address of your local distributor.

# HOTLINE REPORT

*Creation date:* *Created by:*

*Company:* *Contact:*

*Keywords (at least one):*

*Problem type:* ☐ **Bug** ☐ **Improvement** ☐ **Other**

*Summary:*

*Description:*

*Involved operating system(s):*

| | | |
|---|---|---|
| ☐ **All** | ☐ **Unix (all)** | ☐ **PC (all)** |
| | ☐ **HP** | ☐ **Windows 2000** |
| | ☐ **IBM** | ☐ **Windows NT** |
| | ☐ **SGI** | ☐ **Windows XP** |
| | ☐ **SUN** | ☐ **Linux** |
| | ☐ **Other:** | ☐ **Other:** |

*Involved software version(s):*

| | | | | |
|---|---|---|---|---|
| ☐ **All** | ☐ **AMESim (all)** | ☐ **AMERun (all)** | ☐ **AMESet (all)** | ☐ **AMECustom (all)** |
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